PROCEEDINGS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS

Vol. XXXVII Number 1

JANUARY, 1918

Meeting in New York, January 11, 1918
See Section I, page 1

MIDWINTER CONVENTION

New York, February 15-16, 1918

Friday morning	- - -	Circuit Breaker Session
Friday afternoon	- - -	Meter Session
	Informal Dinner	
Friday evening	- - -	Address and Lecture
Saturday morning	- - -	Commutation Session

ADVANCE NOMINATIONS

Attention of members is called to the notice in Section I of this issue regarding advance nominations for Institute officers for 1918-1919. To be valid, such nominations must be received by the Secretary not later than January 25, 1918.

PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXVII
Number 1

JANUARY, 1918

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GEORGE R. METCALFE, Editor.

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVII | **JANUARY, 1918** | **Number 1**

THE 336th INSTITUTE MEETING IN BOSTON, NEW YORK AND CHICAGO

The 336th meeting of the Institute as announced in the December PROCEEDINGS will be an inter-sectional meeting held in Boston, January 8th, New York, January 11th, and Chicago, January 14, 1918. The same paper will be presented and discussed at the three places.

The paper to be presented is given under the Auspices of the Committee on the Economics of Electric Service and is entitled "Effects of War Conditions on the Cost and Quality of Electric Service" by Lynn S. Goodman and William B. Jackson. The paper will be presented at the Boston and Chicago meetings by Mr. Jackson and at the New York meeting by Mr. Goodman. It is published elsewhere in this issue of the PROCEEDINGS and reprints will be available at the meeting.

Non-members of the Institute who are interested in this subject are cordially invited to attend and take part in the meeting:

FUTURE SECTION MEETINGS

Ithaca.—January 18, 1918. Subject: Modern Transmission Line Practise.

Lynn.—January 9, 1918. Subject: Steel Foundry Practise.

Philadelphia.—January 14, 1918. Subject: Specifications Covering the Construction at Crossings or Overhead Lines or Public Utilities.

Pittsburgh.—January 19, 1918. Subject: Generation and Utilization of Power in Steel Mills. Joint Meeting with Association of Iron and Steel Electrical Engineers.

Pittsfield.—January 17, 1918. Subject; Motor Drive in Textile Mills. Speaker, S. B. Paine.

Portland.—January 8, 1918. Subject: Powdered Coal for Fuel. February 8, 1918. Subject: Electric Smelting of Iron.

San Francisco.—January 25, 1918. Subject: Corona at High Altitude.

St. Louis.—January 23, 1918. Subject: Electrical Equipment of New Post Despatch Building.

MEETING OF THE INSTITUTE OF RADIO ENGINEERS, JANUARY 2, 1918

The next meeting of the Institute of Radio Engineers will take place on the evening of Wednesday, January 2, 1918, in Room 2, fifth floor of the Engineering Societies Building, 33 West 39th St., New York, at 8:15 p.m.

A paper on "The Dynatron" will be presented by Dr Albert W Hull, of the General Electric Company. The dynatron is an interesting extension of the hot-cathode electron relay.

Institute members and their friends are cordially invited to attend.

ENGINEERING COUNCIL MEETING, DECEMBER 6, 1917

A meeting of Engineering Council was held on December 6th in the beautifully appointed new board room of the American Society of Civil Engineers, Engineering Societies Building, New York.

A committee which has for some time been searching for a suitable man to act as a permanent secretary for the Engineering Council, the United Engineering Society and for the Engineering Foundation, having concluded their labor, unanimously recommended Mr. Alfred D. Flinn. The resignation of Mr. Calvert Townley, who has held office since the organization of Engineering Council, was accepted with expressions of appreciation for services rendered and Mr. Flinn was elected to the vacancy, his term of office to begin January 1, 1918.

Council adopted a report of its committee on Rules providing a method for electing to its membership additional engineering and technical societies. The rules now adopted go to the governing bodies of the four founder societies for consideration.

The matter of the administration of the National Selective Draft Law with respect to students in engineering schools having been recommended to the consideration of Engineering Council, the following resolution was adopted and was thereupon telegraphed to the Honorable Newton D. Baker, Secretary of War, and General Enoch F. Crowder, Provost Marshall, viz.:

"RESOLVED, The Engineering Council, representing the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers, recognizing the serious responsibility of the Engineer for the successful prosecution of the war, in the many branches of the National service, where highly trained Engineers are required, urges the importance, as a war measure, of maintaining unimpaired the Engineering strength of the Nation, for the successful prosecution of military operations, and for the support of sustaining industries.

"Since Schools of Engineering are the principal sources from which trained Engineers may be drawn, the Engineering Council urges that in the administration of the selective draft the Government should maintain these Schools in full operation, and should take such steps as will enable qualified Engineering students to continue their studies to graduation, if possible, and, in any event, until necessity demands their call for active service.

"This recommendation is made for the sole purpose of insuring the continuous supply of trained Engineers for the future service of the Nation."

STATUS OF ENGINEERING STUDENTS UNDER THE SELECTIVE SERVICE LAW

In view of the great importance of engineering in the prosecution of the war, it is the general feeling among engineers that the best interest of the country both during the war and in the subsequent reconstruction period will be met by conserving to the greatest extent all the engineering talent and ability of the country.

To this end a movement was inaugurated by various engineering societies and engineering colleges for placing the students of engineering colleges in the deferred class under the draft law so as to make it possible for them to complete their regular college course in engineering before entering the service. The great majority of the 1917 graduates of engineering colleges have already enlisted and one-third of the present senior class is also enlisted without waiting to graduate. It is felt to be of the utmost importance to the winning of the war that the supply of college trained engineers should be augmented to the greatest extent possible.

As a result of this movement the following clause has been added by the Provost Marshal General to Section 151 of the Selective Service Regulations:

"Under such regulations as the Chief of Engineers may prescribe a proportion of the students pursuing an engineering course in one of the approved technical engineering schools listed in the

War Department, as named by the school faculty may enlist in the Enlisted Reserve Corps of the Engineer Department and thereafter upon presentation by the registrant to his local board of a certificate of enlistment, such certificate shall be filed with the Questionnaire and the registrant shall be placed in Class V on the ground that he is in the military service of the United States."

The regulations of the Chief Engineers limit this privilege to those students to whom the school issues the following certificate properly attested by the President of the school·

I hereby certify that............ is a regular student of the ...... class in good standing, as a candidate for an Engineering degree at ....and that in the judgment of the faculty of this school, based upon his academic record, supplemented by his relations, with fellow students and by observation of his instructors, he may fairly be regarded as deserving a place in the first third qualitatively of the young men graduating from this institution during the past ten years.

ANOTHER ENGINEER REGIMENT TO BE ORGANIZED

The cooperation of the Institute has been requested in the organization of the 37th Engineers (Electrical Mechanical). This regiment will be organized at Fort Myer, Va., and will be for the purpose of performing electrical installation, operation and maintenance in France.

The officers for the regiment are available from the roster of the Engineer Reserve Corps.

The following information regarding this regiment has been received from the War Department.

The classifications which it is desired to include in the enlisted personnel of the regiment are: Engineers, stationary; motor truck drivers; electricians; cable splicers; linemen; expert test men; wiremen; armature winders; machinists; pipe fitters; carpenters; blacksmiths; handymen; cooks.

The pay of the enlisted men is determined by their military rank. The following is the schedule of pay on foreign service: First Sergeant, $60.00; Sergeant, first class, $60.00; Supply Sergeant, $51.20; Mess Sergeant, $51.20 Stable Sergeant, $51.20; Sergeant, $51.20; Corporal $40.80; Horseshoer, $44.00; Saddler, $40.20; Wagoner, $40.20; Cook, $44.00; Bugler, $33.00; Private, first class, $36.60; Private, $33.00.

All necessary clothing and subsistence is furnished free to enlisted men.

The opportunity to try for promotion as non-commissioned officers will be afforded to every enlisted man as the regiment will be entirely new. The organization will be military as far as training, drills, discipline, etc., is concerned, as it is found that the health and efficiency of the men is in this way most readily maintained.

Persons desiring to join the 37th Engineers should be advised to apply for forms to the Commanding Officer, 37th Engineers, Room 195, War Department, Washington, D. C. No enlistments will be received except by authority of this officer. Men in the draft age, but not yet called, may also make application.

GOVERNMENT SERVICE

Electricians: The next training school for temporary specialists of the Coast Artillery Corps will be opened about March 4, 1918 Men who have had an electrical education equivalent to two years college work or who are thoroughly familiar with electricity and electrical apparatus and are now proficient in mathematics should apply for this course. They will be fitted for Electrician Sergeants, 2d Class who are charged with the care, operation and repair of electrical installations at Coast Artillery posts, which include power plants, telephone systems, searchlights, gasoline engines, cable repairs, etc. The monthly rate of pay is $44.00 for first enlistment, with promotion as vacancies occur to Electrician Sergeant, 1st Class at $51.00 per month; Engineer

$71.00 per month, and Master Electrician at $81.00 per month. All rates of pay are in addition to clothing, quarters, subsistence, and medical attendance.

Applications should be filed at once as follows.

Persons residing in New England States to Commanding Officer, North Atlantic Coast Artillery District, Boston, Mass.: those in Middle Atlantic States to Commanding Officer, Middle Atlantic Coast Artillery District, Fort Totten, New York; those in Southern States to Commanding Officer, South Atlantic Coast Artillery District, Charleston, South Carolina.

Men who are over draft age can enlist after their applications are approved and be entered on the next course. Men who are of draft age cannot voluntarily enlist. If drafted, they should make application for the school through their Division Commander.

WELCOME TO THE AMERICAN SOCIETY OF CIVIL ENGINEERS

On Friday evening December 7, 1917 a meeting under the auspices of the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the American Institute of Electrical Engineers and the United Engineering Society was held in the auditorium of the Engineering Building, 33 West 39th St., New York, at which the American Society of Civil Engineers was formally welcomed into the Fraternity of the founder societies and the occupancy of the enlarged Engineering Societies Building.

Chairman Charles F. Rand, President of the United Engineering Society opened the ceremonies at 8:30 p.m. with a brief address in which he predicted that the coming of the American Society of Civil Engineers into the fraternity of the founder societies would prove a milestone in engineering affairs. He pointed out that certain advantages had already become apparent. The libraries have been merged and the Engineering Council established. Mr. Rand gave credit for a large part of the success of the United Engineering Society to the policies established by its former leader Mr. Gano Dunn, who was then introduced.

Mr. Dunn expressed the welcome of the American Institute of Electrical Engineers to the Civil Engineers. He designated this final union of the four great national engineering societies as the realization of the dreams of such prominent engineers as W. D. Weaver, S. S. Wheeler, C. F. Scott and T. C. Martin.

Mr. Rand next introduced Professor Ira N. Hollis, President of the American Society of Mechanical Engineers. Prof. Hollis in expressing the very strong approval of the Mechanical Engineers in this unification of the engineering body spoke of the opportunity offered to engineers in general to so assist this country in the task which it now faces, that when the historian shall write of the 20th century, he can say it is the engineer who has made science safe for mankind.

Chairman Rand next introduced Dr. Rossiter W. Raymond, Secretary Emeritus of the American Institute of Mining Engineers who welcomed the Civil Engineers on behalf of the Mining fraternity. He outlined the close relationship which has always existed in the fields of operation and the accomplishments of the electrical, mechanical, civil and mining engineers.

Following Dr. Raymond, Mr. William L. Saunders spoke in behalf of the United Engineering Society. He expressed the hope that the union being celebrated, represented not merely a physical contact but was significant of the spirit and purpose of the engineers to get together for service not alone in scientific fields but to take their place in the affairs of civil life.

Mr. George H. Pegram, President of the American Society of Civil Engineers responding for the Civil Engineers earnestly concurred in the necessity for co-operative action among engineers in

general for service to the country and to the advancement of the profession, that will result. This union of the societies in one home should prove a happy augury of the direction in which they are moving and of the endeavor to establish or popularize the profession of engineering.

Mr. Pegram then called upon Mr. George F. Swain, Past-President of the Civil Engineers and member of the Engineering Council, who sa'd in part, as follows: "It seems to me that we have confined ourselves too much to simply two of the purposes of an engineering society; the advancement of knowledge and the making of a high standard for the societies themselves. We have neglected two other things, namely, making the engineering profession felt as a moving force in the community and doing something more for the individual member. We have got to organize, we have got to make ourselves fel in the sta es, in the counties and in the wa ds perhaps. The engineer ought to be a moving force. We have got to cooperate. We have got to pull together. I am glad that this amalgamation has come at this time when the whole world is being reconstructed and we are finding out we can do things that we had no idea we could do."

Mr. Charles Warren Hunt, Secretary of the Civil Engineers and Vice President of the United Engineering Society after a few words then called for the adjournment of the meeting.

A. I. E. E. MEETING IN NEW YORK, DECEMBER 14, 1917

The 335th meeting of the Institute was held at Institute headquarters, 33 West 39th St., New York, December 14, 1917. In the absence of the President, Mr. E. W. Rice Jr., the Senior Vice-President, Mr. B. A Behrend called the meeting to order at 8:20 p.m.

Mr. Behrend called upon Mr. F. W. Peek Jr., who presented the paper by Lloyd N. Robinson entitled "*Phenomena Accompanying Transmission with Some Types of Star Transformer Connections.*" Mr. P. L. Alger then presented his and Dr. A. E. Kennelly's joint paper entitled "*Magnetic Flux Distribution of Annular Steel Laminae.*" Dr. Kennelly made a few supplementary remarks.

Mr. Behrend then opened the discussion which was participated in by the following men: L. W. Chubb, V. M. Montsinger, A. S. McAllister, J. B. Taylor, L. T. Robinson, D. C. Jackson, C. O. Mailloux, A. M. Dudley, George B. Thomas and F. W. Peek, Jr. Closures were than made by P. L. Alger and Dr. Kennelly and the meeting adjourned.

A. I. E. E. DIRECTORS' MEETING DECEMBER 14, 1917

The regular monthly meeting of the Board of Directors was held at Institute headquarters on Friday, December 14, at 3:30 p.m.

There were present: Vice-Presidents, B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y., A. S McAllister, New York; Managers, John B. Taylor, Schenectady, N. Y., C. E Skinner Wilfred Sykes, and Charles Robbins, Pittsburgh, Pa.. N. A. Carle, Newark, N. J., Walter A. Hall, Lynn, Mass., William A. Del Mar, New York, and Secretary F. L. Hutchinson, New York.

Senior Vice-President Behrend presided in the absence of President Rice

The action of the Finance Committee in approving monthly bills amounting to $8,047.92 was ratified.

The report of the Board of Examiners of its meeting held on December 10, 1917, was presented and the actions taken at that meeting were approved.

Upon the recommendation of the Board of Examiners the following action was taken upon pending applications: 109 students were ordered enrolled, 40 applicants were elected to the grade of Associate, 1 applicant was

reinstated to the grade of Member, 6 applicants were elected to the grade of Member, 4 applicants were transferred to the grade of Member, and 1 applicant was transferred to the grade of Fellow.

The Meetings and Papers Committee reported, recommending that the Mid-winter Convention be limited to the two days, Friday, February 15, and Saturday morning, February 16, the entire meeting to be devoted to technical sessions, omitting all entertainment features. This recommendation was approved.

Professor W. I. Slichter, whose term as a representative of the Institute upon the Library Board of the United Engineering Society expires on December 31, 1917, was reappointed for the term of four years ending December 31, 1921.

The Secretary announced that in accordance with Section 87 of the Institute by-laws President Rice would automatically become a member of the John Fritz Medal Board of Award on the third Friday of January, 1918, to succeed Past-President C. O. Mailloux, whose term will expire on that date.

A letter from the Los Angeles Section soliciting the Institute's support for a joint technical library in Los Angeles was referred to the Library Board of the United Engineering Society.

A considerable amount of other business was transacted, reference to which will be found under appropriate headings in this and future issues of the PROCEEDINGS.

NOMINATIONS FOR INSTITUTE OFFICERS FOR 1918-19

As provided in Section 20 of the Institute by-laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1918, by the petition or by the separate endorsement in writing, of not less than fifty members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1918. For the convenience of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available. A member is not limited in the number of candidates he may endorse in this manner.

The officers to be elected are: a President and Treasurer, for the term of one year each, six Vice-Presidents for the term of one year each, and three Managers for the term of four years each.

The Constitution provides that "the President, Vice-Presidents and Managers shall not be eligible for immediate reelection to the same office. A Vice-President shall not be eligible for immediate election to the office of Manager."

For the information of members, the full text of Section 20 of the by-laws, governing the proposal of candidates for nomination, is printed below:

SEC. 20. In addition to the names of incumbents of office, the Secretary shall publish on the "form showing offices to be filled at the ensuing annual election in May" provided for in Article VI of the Constitution, the names, as candidates for nomination, of such members of the INSTITUTE as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty members, received by the Secretary of the INSTITUTE in writing by January 25 of each year.

The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the December and January issue of each year's PROCEEDINGS, and shall be reproduced on the form above referred to.

A. I E. E. HONOR ROLL

Members of the American Institute of Electrical Engineers in Army and Navy service with the United States and her Allies.

This list supplements that published in the December PROCEEDINGS and includes only those members who are in the armed forces and who have responded to the War Service card sent to the membership on Sept. 15, 1917.

Members in Army and Navy service who have not been listed are requested to communicate with Institute headquarters.

ANDERSON, ARVID R.
324th Regiment, Field Artillery.

APPLEGATE, K. P.
Lieutenant, U. S. Navy.

ASHER, LEON
U. S. Navy.

BABCOCK, A. H.
Major, E. O. R. C.

BARROW, GEORGE M.
2nd Lieutenant, E. O. R. C.

BEALL, JOHN C.
First Lieutenant, S. O. R. C.

BELLMAN, JOHN J.
Lieutenant, 9th Coast Artillery, N. Y.

BLAIR, EDWARD J.
Captain, 311th Engineers.

BOLLE, HERMAN A.
Chief Radio Operator, U. S. Navy.

BRINKMEIER, A. E. H.
Lieutenant, junior grade, U. S. N. R. F.

BROCKWAY, R. M.
Second Lieutenant, O. O. R. C.

BUCHANAN, J. L.
Captain, E. O. R. C.

BURNETT, JAMES H.
306th Infantry.

BUTCHER, WILLARD F.
Chief Electrician, U. S. N. R. F.

BUTTERS, J. H.
Captain, 6th District, Australia.

DELAVAL, LEON
65th Battery, 83rd Regiment, French Army.

EUSTIS, T. W.
First Lieutenant, Aviation Section, Signal Corps.

FARLEY, JAMES JOSEPH
Captain, O. O. R. C.

FOURAKER, LEROY L.
Second Lieutenant, 316th Infantry

KEY TO ABBREVIATIONS.

E. O. R. C.—Engineer Officers' Reserve Corps.
S. O. R. C.—Signal Officers' Reserve Corps.
C. A. O. R. C.—Coast Artillery Officers' Reserve Corps.
O. O. R. C.—Ordnance Officers' Reserve Corps.
U. S. R.—United States Reserve.
N. R. F.—Naval Reserve Force.

GIBBS, C. D.
Lieutenant, junior grade, U. S. N. R. F.

HART, PHILIP EWING
2nd Lieutenant, Royal Engineers, France.

HAYS, JOHN C.
Major Q. M., U. S. R.

HEHRE, FREDERICK W.
Lieutenant, junior grade, U. S. N. R. F.

HERRICK, D. C.
Lieutenant, junior grade, U. S. N. R. F.

HUBER, C. J.
Captain, O. O. R. C.

HULL, ROBERT H.
Lieutenant, junior grade, U. S. N. R. F.

KAY, WILLIAM D.
Lieutenant, Sanitary Corps.

LE TOURNEAU, E. H.
Ensign, U. S. S. South Dakota.

LOCKWOOD, A. M.
Sergeant, 343rd Field Artillery.

LULL, LINFORD C.
Second Lieutenant, Aviation Section, S. O. R.C.

LUSH, ARTHUR
Lieutenant, New Zealand Engineers, France.

LYONS, EDWARD J.
124th Field Artillery.

MAXWELL, ALEXANDER
Captain, E. O. R. C.

McCLELLAN, L. N.
First Lieutenant, E. O. R. C.

MESSICK, CHARLES
Lieutenant, junior grade, U. S. N. R. F.

MILLER, HAROLD P.
1st Lieutenant, S. O. R. C.

MILLER, WESLEY C., JR.
Lieutenant, U. S. N. R. F.

NEWLIN, EARL W.
First Lieutenant, 312th Machine Gun Battalion.

OLSEN, HARRY N.
Telegraph Battalion, Signal Corps.

PENGILLY, JOSEPH H.
Captain, E. O. R. C.

PENNINGTON, PAUL
Lieutenant, U. S. N. R. F.

REBER, SAMUEL
Colonel, Signal Corps, U. S. Army.

RICHARDSON, R. E.
Engineering Division, Signal Corps.
RICHTER, HENRY.
Lieutenant, junior grade, U. S. N. R. F.
SCHNYDER, W.
Lieutenant, Royal Engineers.
SHOEMAKER, R. W.
Lieutenant, U. S. N. R. F.
SHULER, WM.
Lieutenant, junior grade, U. S. N. R. F.
SIMPSON, R. C.
Lieutenant Colonel, 9th Infantry Brigade, Australian Forces.
SLOCUM, W. W.
Lieutenant, U. S. N. R. F.
SMILEY, GLENN W.
First Lieutenant, Aviation Section, S. O. R. C.
SPENCE, JAMES
Lieutenant, Royal Engineers, British Expeditionary Force.
STAIR, JACOB, JR.
Lieutenant, junior grade, U. S. N R. F.
STRECKER, GEORGE M.
Coast Artillery.
STREET, GEORGE T.
Captain, 309th Engineer Train.
SULTAN, WALTER D.
Aviation Section, Signal Corps.
TRIPPLE, GEORGE
First Lieutenant, E. O. R. C.
WAHL, JAMES H.
Lieutenant, junior grade, U. S. N. R. F.
WALLACE, W. S.
Lieutenant, junior grade, U. S. N. R. F.
WATSON, JAMES L.
Aero Service, U. S. Navy.
WRIGHT, GEO.
Lieutenant, junior grade, U. S. N. R. F.
Total including previous list 540.

PAST SECTION MEETINGS

Baltimore.—November 9, 1917, John Hopkins University. Address by Prof. Jos. S. Ames on "Military Aeronautics" Attendance 130.

Chicago.—November 26, 1917, Western Society of Engineers Rooms. Paper: "Engineering Data Necessary for an Electric Rate Determination" by Bert H. Peck. Moving pictures showing the training of our soldiers at Camp Grant as prepared by the Chicago Daily News. Attendance 145.

Cleveland.—November 19 1917, Hotel Statler. Paper: "Gas-Electric Automobiles" by R. W. Knowles Attendance 54.

Denver.—November 17, 1917, Denver Athletic Club. Address by Dean Milo S. Ketcham on "Engineering Education as Affected by the War." Attendance 28.

Detroit-Ann Arbor.—November 9, 1917. Detroit Board of Commerce. Illustrated address by Mr. A. M. Dudley on "Speed-Torque Characteristics of Industrial Motors." Attendance 80.

Ithaca.—November 16, 1917, Franklin Hall. Address by Mr. S. T. Dodd on "Electric Locomotives." Attendance 38.

Los Angeles.—November 13, 1917, Angelus Hotel. Paper: "Plan and Organization of the Pacific Telephone and Telegraph Company," by L. A. Gary. Attendance 25.

November 24, 1917.—Mt. Wilson Observatory. Two day trip to Mt. Wilson Observatory under auspices of Joint Committee of the Technical Societies of Los Angeles. Attendance 112.

Lynn.—November 7, 1917, Casino Hall. Illustrated address by Major A. C. Thompson on "How Electricity Fires Our Big Guns." Also address on the Red Cross by Ralph W. Reeve.

November 21, 1917, G. E. Hall. Address by Mr. J. A. Capp on "Selection of Materials of Manufacture and the Use of Specifications." Also short address by Dr. C. H. Bangs on "Sanitary Engineering and Medical Engineering in the War."

November 30, 1917, Casino Hall. Symposium on Cotton by Messrs. Theodore H. Price and E. W. Sargent. Motion pictures showing features of the cotton industry. Attendance 600.

December 5, 1917, G. E. Hall. Subject: Motors. Speakers: J. A. Dalzell, C. H. Haddrell, J. B. Wiard, W. B. Seigle, and W. B. Blake. Attendance 375.

Milwaukee.—November 14, 1917, City Club. Illustrated lecture by Mr. B. E. Fernow, Jr., on "Design and Application of Magnetic Clutches." Attendance 200.

Minnesota.—November 21, 1917, University of Minnesota. Papers: (1) "Balancing the Aesthetic and Utilitarian in an Electric Lighting Installa-

tion," by Francis A. Vaughn; (2) "Some Considerations Regarding Interior Lighting," by Frederick M. Mann. Attendance 50.

December 7, 1917, University of Minnesota. Address by Col. Wildman on "Wartime Work of the U. S. Signal Corps in Aviation and Electrical Communication." Attendance 250.

Panama.—November 18, 1917, Balboa, C. Z. Papers: (1) "Determination of Transformer and Induction Motor Characteristics by Means of the Circle Diagram Method," by Leo Gutting; (2) "Determination of Induction Motor Characteristics by Means of Steinmetz's Analytical Method," by Walter L. Hersh. Attendance 32.

Pittsburgh.—December 11, 1917, Carnegie Institute. Address by General Hulings on "Why Do We Fight." Attendance 75.

Pittsfield.—November 22, 1917, Masonic Temple. Illustrated lecture by Prof. Wm. L. Cathcart on "The War by Land and Sea." Attendance 800.

December 6, 1917, Hotel Wendell. Lecture by Mr. F. A. Lidbury on "Electrochemical Industries and the War." Attendance 215.

Portland.—November 20, 1917. Multnomah Hotel. Illustrated address by Mr. Preston S. Millar on "Illuminating Aspects of Street Lighting." Joint meeting with local section of N. E. L. A. Attendance 39.

Rochester.—November 23, 1917, Rooms of Rochester Engineering Society. Paper: "Electrocardiograph, an Instrument for Measuring Electrical Impulses from the Heart," by E. W. Jackson and C. T. Wallis. Attendance 25.

San Francisco.—November 23, 1917, Engineers Club. Paper: "Construction of the Hetch-Hetchy Project," by M. M. O'Shaughnessy. Attendance 90.

Schenectady.—November 23, 1917, Edison Club. Illustrated address by Mr. Alexander Dow on "Production of Electric Power from Coal." Attendance 165.

December 7, 1917, Union College Gymnasium. Illustrated lecture by Mr. Simon Lake on "The Submarine." Attendance 1650.

Seattle.—October 16, 1917, Arctic Club Building. Paper: "Voltage Regulation of the Connected Transformer," by L. F. Curtis. Chairman C. E. Magnusson gave brief summary of his experiences during his recent trip in the east. Attendance 17.

Spokane.—November 16, 1917, Chamber of Commerce. Illustrated lectures by Messrs. J. W. Conley and C. W. Twitchell on "Starting, Ignition, and Lighting of Automobiles." Mr. D. Riegal gave a moving picture of the manufacture of the Dodge car. Attendance 47.

St. Louis.—November 28, 1917, Engineers Club. Motion picture entitled "The Benefactor" was obtained through courtesy of General Electric Company. The film was a portrayal of life of Thomas A. Edison. Attendance 25.

Toledo.—October 23, 1917, Toledo Commerce Club. Address by Mr. M. E. Grah on "The Underground Cable System of Toledo." Attendance 20.

November 28, 1917, Zenobia Hall. Illustrated address by Mr. Johnson on "Illumination." Attendance 150.

Toronto.—November 16, 1917, Engineers Club. Papers: (1) "A Commercial Method of Ratio-ing Current Transformers," by Harry S. Baker; (2) "Demand Meters," by Perry A. Borden; (3) "Relays," by C. W. Baker. Attendance 55.

Vancouver.—November 5, 1917, University Club. Nomination of officers as follows—chairman, R. F. Hayward; secretary, T. H. Crosby; executive committee, E. P. LaBelle, C. N. Beebe, and L. B. Philpot.

November 26, 1917. Board of Trade Building. Paper: "The Present Trend and Development of Electrical Business with Possibilities for the Future," by M. L. G. Robinson.

PAST BRANCH MEETINGS

Arkansas University.—November 26, 1917, Engineering Hall. Papers: (1) "Use of Electricity in the European War," by L. S. Starbird; (2) "War Telephone Needs," by F. B. Mason. Address by Prof. Wadleigh on "The Oscillograph." Attendance 12.

Armour Institute.—November 22, 1917, Electrical Engineering Lecture Room. Illustrated lecture on "The Electrical Measurement of Thermal Conductivity," by Prof. J. C. Peebles. Attendance 21.

December 5, 1917, Electrical Engineering Lecture Room. Illustrated address by Mr. V. A. Hain on "Industrial Electrical Heating." Attendance 20.

Carnegie Institute of Technology.—November 21, 1917. Paper: "Industrial Applications," by A. M. Dudley. Attendance 25.

Clarkson College of Technology.—December 4, 1917. Paper: "Development of Railway Motors and Westinghouse Student Course," by P. H. Smith. Attendance 40.

Colorado State Agricultural College.—November 13, 1917, Electrical Building. Paper: "Interior Lighting," by Mr. Richards.

University of Colorado.—November 15, 1917, Engineering Building. Address by Mr. Rankine on "The Regulation of Public Utilities." Attendance 15.

December 6, 1917. Engineering Building. Illustrated lecture on "The Development of Electric Lighting," by Prof. Jenkins.

University of Kansas.—November 2, 1917, Marvin Hall. Papers: (1) "Applications of A-C. Motor Controllers," by C. Lynn; (2) "Direct-Current Motor Controllers," by H. F. Lutz. Attendance 24.

December 5, 1917, Marvin Hall. Address by Mr. C. A. Keener on "Outdoor Flood Lighting." Attendance 23.

Kansas State Agricultural College.—November 15, 1917, Denison Hall. Papers: (1) "Regenerative Braking"; (2) "Electrifying an Old Town"; (3) "Repairing an Old Storage Battery System"; (4) "My Thesis." Attendance 36.

Lafayette College.—November 10, 1917, Pardee Hall. Papers: (1) "Electricity in the Steel Industry"; (2) "Electrochemical Industries and Water Power Development"; Attendance 15.

November 17, 1917, Pardee Hall. Papers: (1) "Single-Phase Power from Central Stations"; (2) "Improvement of Off-Peak Load." Attendance 17.

Massachusetts Institute of Technology.—November 27, 1917, Smith Hall. Lecture by Dr. Lowenstein on "New Process of Producing Pig Iron at an Increased Output of 30 per cent." Attendance 115.

University of Michigan.—November 16, 1917. Address by Prof. B. F. Bailey on "The Manufacture of Electric Machinery." Attendance 40.

University of Missouri.—November 19, 1917, Y. M. C. A. Building. Paper: "Recent Developments in Illumination," by J. O. Walz. Attendance 27.

December 3, 1917, Missouri Union. Paper: "The Legal Status of Interference between Overhead Electric Tower Transmission and Telephone Lines," by J. A. Whitlow. Attendance 26.

University of Minnesota.—December 3, 1917. Election of officers to fill vacancies due to present members entering the service, as follows—chairman, Russel Ross; secretary-treasurer, Ray McKibben. Motion pictures showing electrification of railroads. Attendance 35.

Montana State College.—November 14, 1917, Electrical Building. Address by Prof. J. M. Hamilton on "The Electrical Engineer and the War." Attendance 25.

November 16, 1917, Lyric Theatre. Motion picture "King of the Rails," by courtesy of General Electric Company. Attendance 155.

University of Nebraska.—December 5, 1917, Electrical Engineering Labora-

tory. Symposium on "Experiences in Telephone Work." Attendance 12.

North Carolina College of Agricultural and Mechanical Arts.—November 28, 1917. Lecture by Mr. A. A. Dixon on "Ionization." Attendance 15.

Ohio Northern University.—November 21, 1917. Address by Prof. McEachron on "High-Voltage Testing." Attendance 18.

Ohio State University.—November 23, 1917, Robinson Laboratory. Address by Mr. L. R. Lee on Construction of the Walnut Power Plant of the Col's. R. P. & L. Attendance 42.

University of Oklahoma.—November 9, 1917, Engineering Building. Papers: (1) "Valuation of Public Utilities," by C. Whitwell; (2) "Alternating-Current Transformers," by C. T. Hughes. Attendance 20.

Oregon Agricultural College.—November 21, 1917. Addresses as follows, (1) "Growth of Electrical Laboratory at O. A. C." by Prof. S. H. Graf; (2) "The Engineer, Efficiency and Democracy," by Prof. O. T. Goldman. Attendance 31.

Syracuse University.—November 15, 1917. Debate—Resolved, that electrical energy can be manufactured more cheaply by a central station than by an isolated plant. Affirmative, L. N. Moore; negative, R. Franklin. Attendance 13.

November 22, 1917. Paper: "History of the Center Span of the Quebec Bridge," by E. C. Givens. Attendance 11.

December 6, 1917. Paper: "Electric Arc Welding and Cutting of Metals with the Electric Arc," by H. F. Buchanan. Attendance 11.

Agricultural and Mechanical College of Texas.—December 12, 1917, Electrical Engineering Building. Illustrated lecture on "Illumination," by F. C. Bolton. Attendance 15.

University of Virginia.—November 16, 1917, Electrical Laboratory. Brief addresses as follows: (1) "The Manufacture of Three-Inch Shells," by J. E. B. Stuart; (2) "The Newport News Shipyards," by C. P. Livesay; (3) "Construction of a Logging Railroad," by P. F. Brown. Attendance 12.

December 5, 1917, Electrical Laboratory. Papers: (1) "Searchlights," by Charles Henderson; (2) "Magnetic Separator Pulleys," by J. A. Evans; (3) "Electro-Fixation of Nitrogen," by John M. Nalle. Attendance 12.

Washington State College.—November 23, 1917. Paper: "The Relation of Engineering to the War," by Prof. Carpenter. Attendance 52.

University of Washington.—December 4, 1917, Forestry Hall. Paper: "The Competition of Small Hydro-Electric Plants with Large Power Plants,"by C. W. Harris. Attendance 9.

Worcester Polytechnic Institute.—November 16, 1917, Electrical Engineering Building. Paper: "The Electrical Engineer in Germany and England under War Conditions," by Carlyle A. Atherton. Attendance 230.

December 7, 1917, E. E. Lecture Hall. Paper: "The Other Half of Engineering," by George M. Eaton. Attendance 70.

Yale University.—November 23, 1917. Paper: "Some Phases of the Electric Furnace," by Woolsey McA. Johnson. Atetndance 76.

December 14, 1917. Paper: "Long Distance Transmission of Power," by Percy H. Thomas. Attendance 40.

ASSOCIATES ELECTED DECEMBER 14, 1917

Recommended for Election by the Board of Examiners, December 10,1917.

BAILEY, JOHN BOWEN, Transformer Engineer, Duncan Electric Mfg. Co., Lafayette, Ind.

*BEYER, JESSE WILLIAM, Instructor in Electrical Engineering, State College of Washington; res., 702 Linden Ave., Pullman, Wash.

CARMAN, EDWARD HORACE, JR., Electrical Inspector, Southeastern Underwriters' Association; res., 26 Maddox Drive, Atlanta, Ga.

CLARKE, CHARLES JOSEPH, Junior Electrical Engineer, Public Service Commission, New York, N. Y.; res., Oakwood, Staten Island, N. Y.

CLIFTON, HENRY ENOS, Standardizing Laboratory, General Electric Co.; res., 115 Nott Terrace, Schenectady, N. Y.

CORNELIUS, CLINTON CAMPBELL, Power Dept., United Railways Company, 3869 Park Ave. St. Louis, Mo.

COXE, FRANCIS EDWIN, Electrical Engineer, Piedmont Railway & Electric Co., Burlington, N. C.

*CRITCHFIELD, ROBERT MILLEN, Designing Engineer, Industrial Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

*DAVIS, GEORGE EDWARD, Testing Dept., General Electric Co.; res., 231 Seward Place, Schenectady, N. Y.

DICKSON, FRANK CLAYTON, Owner of Generator, Motor, Magneto & Battery Repair Shop; res., 402 E. Ross Ave., Tampa, Fla.

*DODGE, HAROLD FRENCH, Elec. Engr., Transmission Dept., Western Electric Co., New York, N. Y.; res., 20 Covert St., Port Washington, L. I., N. Y.

*DOOLITTLE, FRANKLIN MALCOLM, Trans. & Protection Engineer, So. New England Tel. Co.; res., 174 Bradley St., New Haven, Conn.

DUSTIN, CHARLES, in charge of Mechanical & Electrical Depts., Kennesott Copper Corp., Latouche, Alaska.

GIELOW, ERNEST L., Manager, Schweitzer Machine Co., 326 E. Washington St., Phoenix, Ariz.

GLEDHILL, JOHN WILLIAM, Charge of Elec. Construction & Maintenance, Central Dyestuff & Chemical Co.; res., 19 Tichenor St., Newark, N. J.

*HARVEY, EVERETT, Engg. Asst., Plant Dept., Western Union Telegraph Co., 195 Broadway, New York, N. Y.

*HOWARD, THORNTON WAYNE, Testing Dept., General Electric Co.; res., 1001 Delamont Ave., Schenectady, N. Y.

LEAVITT, ALBERT JOSEPH, Electrical Designer and Engineer, White, Weld & Co., 111 Devonshire St., Boston; res., Roslindale, Mass.

*LEVERING, ROSIER WILLIAM, Supt., Lafayette Div., Ft. Wayne & Northern Indiana Traction Co., Lafayette, Ind.

MAC LACHLAN, A., Sales Manager, Detroit Fuse & Mfg. Co., 1400 Rivard St., Detroit, Mich.

METZGER, G. C., Hydroelectric Operator, St. Croix Power Co., Somerest; res., Apple River Falls, Wis.

MYSHENKOFF, CONSTANTINE S., Assistant Chief of Department for Suburban Electrification, Moscow-Kazah Railway; res., 40 Pokrowka, Moscow, Russia.

NELSON, JAMES R., Supt. of Power House, San Joaquin Light & Power Co., Springville, Cal.

NUGENT, HOWARD MORGAN, Engineering Dept., Otis Elevator Company; res., 85 N. Broadway, Yonkers, N. Y.

O'CONNELL, JAMES, JR., Inspector in Charge of Inside Wiring for Constructing Quartermaster, Camp Mead, Md.; res., 2126 1st St. N. W., Washington, D. C.

OUSLER, GEORGE WALTER, Engineering Dept., Duquesne Light Co.; res., 5529 Ellsworth Ave., Pittsburgh, Pa.

PYLES, RICHARD MILTON, Superintendent, Meter Dept., Sao Paulo Tramway Light & Power Co., Sao Paulo, Brazil, S. A.

RICHARDS, ARTHUR FRANCIS WARD, Electrical Engineer, W. T. Glover & Co. Ltd., Trafford Park, Manchester, England.

ROBINSON, ROBERT B., Engineering Dept., Duquesne Light Co., Duquesne; res., 5801 Hayes St., Pittsburgh, Pa.

ROGERS, CARL ERNEST, Draftsman, Montreal Public Service Corp.; res., 1322a Chabot St., Montreal, Quebec.

ST. CLAIR, BYRON W., Standardizing Laboratory, General Electric Co., West Lynn; res., 61 Bacheller St., E. Lynn, Mass.

*SHIPMAN, CHARLES F., Statistical Dept., H. L. Doherty & Co., 60 Wall St., New York, N. Y.

SIMPSON, ERNEST L., Assistant Superintendent, Ft. Wayne Works, General Electric Co.; res., 605 Wildwood Ave., Ft. Wayne, Ind.

SMITH, WARREN RIDLEY, Officer-in-Charge, U. S. Naval Radio Station, Sayville, N. Y.

SPRARAGEN, WILLIAM, Instructor in Electrical Engineering, Oklahoma A. & M. College, Stillwater, Okla.

STEWART, CHARLES C., Electrical Engineer, Dewey Portland Cement Co.; res., 1235 Creek Ave., Dewey, Okla.

UTLEY, Thomas Murphy, Chief Electrician, Union Pacific Coal Co., Superior, Wyo.

WERNER, HARRY G., Assistant Engineer, Philadelphia Electric Company, 820 Dauphin St.; res., 6243 Ogontz Ave., Philadelphia, Pa.

WILSON, KLABURN BICKERTON, Electrical Draftsman & Engineer, Sargent & Lundy, Chicago; res., 715 Gunderson Ave., Oak Park, Ill.

WOLCOTT, HAROLD L., Asst. to Light, Heat & Power Supt., Nobel Works, Canadian Explosives Ltd., Nobel, Ontario, Canada.

*Former enrolled students.

Total 40.

MEMBERS REELECTED DECEMBER 14, 1917

LLOYD, ROBERT MCALLISTER, Consulting Engineer, 149 West 36th St.; res., 108 East 82nd St., New York, N. Y.

MEMBERS ELECTED DECEMBER 14, 1917

ALLEN, HARRY VASS, Senior Asst. Elec. Engr., Dept. Water Supply, Gas & Electricity, New York; res., 301 Vanderbilt Ave., Brooklyn, N. Y.

ELTRINGHAM, ROBERT L., Electrical Engineer, Industrial Accident Commission of the State of California, 205 Underwood Bldg., San Francisco, Cal.

MCRAE, WALTER ROBINSON, Master Mechanic, Toronto Railway Co.; res., 48 Rose Hill Ave., Toronto, Ontario, Canada.

PERRY, ALLEN MASON, Engineering Editor, *Electrical World*, 239 W. 39th St.; res., 108 Elwood St., New York, N. Y.

STOCKLE, ERWIN R., Electro-Physicist, The Cutler-Hammer Mfg. Co.; res., 298 Ninth St., Milwaukee, Wis.

WELLHOUSE, FREDERICK J., Electrical Engineer, Switchboard Dept., Westinghouse Elec. & Mfg. Co., Boston; res., Newton Highlands, Mass.

TRANSFERRED TO THE GRADE OF FELLOW DECEMBER 14, 1917

LYON, JESSE D., Consulting Engineer, Cincinnati, O.

TRANSFERRED TO THE GRADE OF MEMBER DECEMBER 14, 1917

DUFFY, FRANK J., General Foreman, Electrical Dept., D. L. & W. R. R., Scranton, Pa.

FOX, MAURICE EDWARD, Chief Electrical Engineer, Edison Accumulators, Ltd., London, England.

FULLER, LEONARD FRANKLIN, Chief Electrical Engineer, Federal Telegraph Co., San Francisco, Cal.

SMITH, HAROLD WHITMORE, Electrical Engineer, Dept. of Works & Railways, Commonwealth Government, Melbourne, Australia.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on December 14, 1917, recommended the following member of the Institute for transfer to the grade of membership indicated. Any objection to this transfer should be filed at once with the Secretary.

To Grade of Fellow

CARPENTER, HUBERT VINTON, Dean of Mechanic Arts and Engineering, State College of Washington, Pullman, Wash.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before January 31, 1918.

Adams, C. S., New London, Conn.
Allamong, J. W., Philadelphia, Pa.
Allen, G. Y., Washington, D. C.
Applegate, R. H., Cleveland, Ohio.
Armstrong, R. McK., Portland, Ore.
Balmford, J. A., Ampere, N. J.
Bass, L. B., Atlanta, Ga.
Bauschpies, F. R., Philadelphia, Pa.
Becker, A. N. (Member), Milwaukee, Wis.
Bennett, C. B., St. Louis, Mo.
Benson, R. J., St. Louis, Mo.
Bergstresser, H. F., Emaus, Pa.
Benjamin, J. C., New York, N. Y.
Benz, W. K., Monroe, Va.
Beyerle, W. H., So. Bethlehem, Pa.
Birren, E. G., Chicago, Ill.
Blackman, L. S., San Francisco, Cal.
Blake, R. I., San Francisco, Cal.
Blatherwick, A. B., Puget Sound, Wash.
Boland, C. St. C., Washington, D. C.
Bostwick, T. J., Pittsburgh, Pa.
Browning, S. D., New York, N. Y.
Charme, L. D., Charlestown, Mass.
Cole, W. C., San Francisco, Cal.
Conklin, A., Milwaukee, Wis.
Cooper, L. W., New York, N. Y.
Cox, H. E., Birmingham, Ala.
Dana, A. S., New York, N. Y.
Darrah, J. L., Mineral Point, Wis.
Darrow, W. E., New York, N. Y.
Davis, R. W., Cincinnati, Ohio
Dellinger, L. M., Pittsburgh, Pa.
Dewhurst, R. M., Hamilton, Ont., Can.
Dible, H. J., Pittsburgh, Pa.
Druart, L. O., Rockford, Ill.
Duncan, J. R., Lexington, Ky.
Eisman, C. E., Schenectady, N. Y.
Ellis, E. R., (Member), New York, N.Y.
Felker, P. H., Pittsburgh, Pa.
Finch, S. C., New York, N. Y.
Foskett, E. L., Jr., New York, N. Y.
Fox, A. C., (Member), St. Paul, Minn.
Freas, H. L., (Member), New York, N.Y
Freepartner, J. J., Seattle, Wash.
Garvey, W. S., Duluth, Minn.
George, L. E., Hopewell, Va.
Given, E. B., Boston, Mass.
Glancy, R. C., Philadelphia, Pa.
Goldstene, A. B., New York, N. Y.
Graham, R. W., Annapolis, Md.
Gramm, J. R., Takoma Park, D. C.
Griffin, J. D., (Member), Johannesburg, S. A.
Hamdi, A. F., New York, N. Y.
Hanchette, D. N., Cleveland, Ohio
Harlan, T. C., Chicago, Ill.
Harris, C. F., New York, N. Y.
Harrison, C. W., Birmingham, Ala.
Harseim, H., Philadelphia, Pa.
Headley, W. E., Missoula, Mont.
Helzer, A. E., Chicago, Ill.
Henderson, C. C., Joplin, Mo.
Hendricks, L. W., Van Nest, N. Y.
Heron, L. M., (Member), Washington, D. C.
Hexamer, W. G. H., (Member), Chester, Pa.
Hightower, C. R., Trenton, N. J.
Holmes, G., New York, N. Y.
Hubbell, L. S., San Francisco, Cal.
Innes, F., Detroit, Mich.
Jacobs, A. M., (Member), New York, N. Y.
Jacoby, A. B., Middletown, Ohio
Johnson, E. W., Minneapolis, Minn.
Kidd, G. E., Newport News, Va.
Kiralfy, A.E., (Fellow), New York,N.Y.
Klauder, L. T., Philadelphia, Pa.
Kleberg, A. L., Kingsville, Tex.
Knapp, P. R., Toledo, Ohio
Knox, R. W., Lead, So. Dakota
Kuhlman, H. H., Minneapolis, Minn.
Landis, K., Chicago, Ill.
Leach, A. W., Chicago, Ill.
Leach, H. B., New York, N. Y.
Leonard, H. C., Newark, N. J.
Lewison, E. K., Canton, Ohio
Lindsey, G. H., Rochester, N. Y
Logan, H. S., Butte, Mont.
Lundberg, E. W., St. Louis, Mo,

Lundgren, A. N., Chicago, Ill.
Lunsford, R. L., Ampere, N. J.
Lynes, G. M., Annapolis, Md.
MacCalla, P. S., Camp Meade, Md.
MacGillivray, R. H., New York, N. Y.
Mann, H. A., Rockland, Mass.
Mansfield, P. B., Erie, Pa.
Maurer, F. C., Columbus, Ohio
Mayers, H. R., San Francisco, Cal.
Merrill, G. W., Boston, Mass.
Mettler, A. H., Lead, So. Dakota
Miller, F. H., Washington, D. C.
Miller, L. E., Cleveland, Ohio
Moreland, E., Portland, Ore.
Morris, G. T., (Member), Washington, D. C.
McDowell, I. W., Chicago, Ill.
McGovern, M. T., Schenectady, N. Y.
McNally, J. W., New York, N. Y.
Nafzger, E., E. Pittsburgh, Pa.
Nomof, M., Jr., New York, N. Y.
O'Connor, A., Boston, Mass.
Olson, S. A., New York, N. Y.
Parsons, G. M., Syracuse, N. Y.
Parsons, O. D., New York, N. Y.
Penn, J. G., Detroit, Mich.
Petrie, J. M., (Member),Edwardsport, Ind.
Poling, C. E., Cincinnati, Ohio
Prince, W. E., Boston, Mass.
Rathbun, H. J., Palo Alto, Cal.
Raube, W. C., Schenectady, N. Y.
Rehman, N. J., Newark, N. J.
Robley, R. R., Portland, Ore.
Samuel, E., Wilmington, Del.
Sawyer, W. B., San Francisco, Cal.
Schott, R. C., E. Pittsburgh, Pa.
Schroeder, C. W., New York, N. Y.
Schroeter, J. P., Milwaukee, Wis.
Shugren, M. U., Denver, Colo.
Sinclair, L. B., Washington, D. C.
Slater, H. C., St. Louis, Mo.
Smith, W. C., College Station, Texas
Stage, R. C., Philadelphia, Pa.
Stehman, E. H., Pittsburgh, Pa.
Stein, S. M., New York, N. Y.
Stevenson, O. H., Naches, Wash.
Stotz, J. K., Crafton, Pa.
Strauss, H. L., New York, N. Y.
Styer, C. A., Annapolis, Md.
Tallmadge, H. A., International Falls, Minn.
Teegarden, C. H., (Member), Washington, D. C.
Tharlet, P. P., Chillicothe, Ohio
Thatcher, G. R., Chicago, Ill.
Thompson, J. G., Philadelphia, Pa.
Thompson, M. T., New York, N. Y.
Tinkey, O. G., Champaign, Ill.
Walker, F. J., New York, N. Y.
Walters, G. R., Yuma, Ariz
Ward, J. A., Casper, Wyoming
Webber, L. G., Boston, Mass.
Weilbacher, W. C., Detroit, Mich.
Weiss, T., Milwaukee, Wis.
Wells, G. R., Madison Wis.
Wensley, R. J., (Member), E. Pittsburgh, Pa.
Wenzel, S. H., Boston, Mass.
Wood, E. E., New York, N. Y.
Woolfolk, R. B., New York, N. Y.
Whiteman, C. A., Pittsfield, Mass.
Wickersheim, L. W., New York, N. Y.
Wiecks, J. F., Spokane, Wash.
Wieseman, R. W., Schenectady, N. Y.
Wiltberger, C. F., Philadelphia, Pa.
Winder, C. A., Niagara Falls, N. Y.
Zajac, A., Erie, Pa.
Zelinger, W., New York, N. Y.
Z mmerman, M. V., Birmingham, Ala.
Zuehcke, E. F., Escanaba, Mich.
Total 162.

STUDENTS ENROLLED DECEMBER 14, 1917

9261 Wolfinger, W. C., Lafayette Coll.
9262 Kennedy, T. W., Cornell Univ.
9263 Handwerger, H., Cornell Univ.
9264 Pannabaker, J. J., Carnegie Inst. of Tech.
9265 Borchardt, B., Univ. of Cal.
9266 Hill, W. L., Univ. of Cal.
9267 Burke, W. F., Univ. of Cal.
9268 Ciprico, J. O'N., Univ. of Cal.
9269 Woods, P. H., Univ. of Cal.
9270 Vernon, F. H., Univ. of Cal.
9271 Rich, L. J., Univ. of Cal.
9272 Robinson, S., Union Univ.
9273 South, C. K., Ohio No. Univ.
9274 Schoenfeld, E. H., Kansas Univ.
9275 Limbocker, W. E., Kansas Univ.
9276 Shughard, C. L., Kansas Univ.

9277 Gish, H. J., Kansas Univ.
9278 Neumann, W. R., Kansas Univ.
9279 Shreve, J. D., Kansas Univ.
9280 Newton, J. E., Univ. of Wis.
9281 Smith,L.M., Worcester Poly.Inst.
9282 Lynde, W. L., Ohio No. Univ.
9283 Moore, L. H., Univ. of No. Dak.
9284 Marsh, E. L., Univ. of No. Dak.
9285 Berry, E. F., Univ. of No. Dakota
9286 Yorn, J. J. C., Purdue Univ.
9287 Graeter, R. M., Purdue Univ.
9288 Williams, T. S., Purdue Univ.
9289 Ohmart, G. L., Purdue Univ.
9290 Ruggles, L. L., Purdue Univ.
9291 Love, E., Purdue Univ.
9292 Conner, H. L., Purdue Univ.
9293 Kinley, C. B., Purdue Univ.
9294 John, K. B., Purdue Univ.
9295 Schweig, E. S., Purdue Univ.
9296 Crosby, F. H., Purdue Univ.
9297 Stocker, E. K., Purdue Univ.
9298 Hansell, C. W., Purdue Univ.
9299 Zinn, M., Purdue Univ.
9300 Harris, F. H., Purdue Univ.
9301 Eames,W.F.,CarnegieInstof.Tech.
9302 Gordon, J. L., School of Engg. of Milwaukee
9303 Arnold,E.H.,Armour Inst.of Tech.
9304 Shotwell, H. H., Armour Inst. of Tech.
9305 Sedlauk,R.J.,ArmourInst.of Tech.
9306 Throop,A.R.,ArmourInst.of Tech.
9307 Joslyn,R.O.,Armour Inst. of Tech.
9308 Veremis, M. C., Armour Inst. of Tech.
9309 Morgan, R. D., Armour Inst. of Tech.
9310 Nalle, J. M., Univ. of Virginia
9311 Stuart, J. E. B., Jr., Univ. of Va.
9312 Philips, J. H., Univ. of Oklahoma
9313 Holland, L. B., Univ. of Oklahoma
9314 Biggers, J. D., Univ. of Oklahoma
9315 Walker, L. A., Univ. of Okla.
9316 Alexander, C. B., Univ. of Okla.
9317 Brown, H. L., Univ. of Oklahoma
9318 Jones, J. P., Univ. of Oklahoma
9319 Garrison, D., Yale Univ.
9320 McBerty, F. H., Cornell Univ.
9321 Jones D. M., Union Univ.
9322 Carroll, P., Univ. of Mich.
9323 Cramer, C. H., Univ. of Mich.
9324 Raymond, E. E., Univ. of Mich.
9325 Sellke, F. A., Univ. of Mich.
9326 Lenick, J., Univ. of Mich.
9327 Givrigian, S. V., Univ. of Mich.
9328 Connell, A. C., Univ. of Mich.
9329 Engle, M. D., Univ. of Mich.
9330 Collins, H. W., Univ. of Mich.
9331 Parks, R. C., Univ. of Mich.
9332 Stuefer, W. G., Univ. of Mich.
9333 Yost, N. S., Univ. of Mich.
9334 Klager, O. C., Univ. of Mich.
9335 Stanley,T.H.,A.&M. Coll. of Tex.
9336 Evans, J. A., Univ. of Va.
9337 Grenha, A. A., School of Engg. of Milwaukee
9338 Call, L. L., Univ. of Wis.
9339 Allen, C. S., Lafayette College
9340 Liang, W. P., Univ. of Wis.
9341 Keener, C. A., Univ. of Kans.
9342 La Roque, H. B., Yale Univ.
9343 Sheppard, H. W., Carnegie Inst. of Tech.
9344 Thuerk, H. C., Purdue Univ.
9345 Sinclair, B. G., Univ. of Wash.
9346 Maiers, M. J., School of Engg. of Milwaukee
9347 Lowcock, H., School of Engg. of Milwaukee
3948 Koch, C J., School of Engg. of Milwaukee
9349 George, B. J., Univ. of Missouri
9350 Clark, E. E., So. Dak. State School of Mines
9351 Behr, L., Cornell Univ.
9352 Kurtz, C. A. R., Cornell Univ.
9353 Lasher, R. E., Cornell Univ
9354 Evans, E. R., Cornell Univ.
9355 Hsu, K., Cornell Univ.
9356 Henderson, E. G., Cornell Univ.
9357 Migueis, H. J., School of Engg. of Milwaukee
9358 Christie, A. L., Univ. of Michigan
9359 Verschoor, P., Univ. of Michigan
9361 Clark, G. A., Univ. of Michigan
9362 Molina, J., School of Engg. of Milwaukee
9363 Skrainka, W., Washington Univ.
9364 Henderson, C., Univ. of Virginia
9365 O'Leary, J., Villanova College
9366 Swanson,E.S.,Chicago,Tech.Coll.
9367 Washakas,F.J.,ChicagoTech.Coll.
9368 Stringham, R. H., Chicago Tech. College
9369 Rehorst, A., Chicago Tech. Coll.

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street.

Harry H. Blades
(former address)
70—12th St. South,
Minneapolis, Minn.

Charles H. Feige
(former address)
149 West 74th St.,
New York, N. Y.

Sydney J. Hurd
(former address)
4433 Prairie Ave.,
Chicago, Ill.

Wm. P. Lewis
(former address)
Cohoes Elec. Power Co.,
Cohoes, N. Y.

Sulpen Sully
(former address)
1723 East Boulevard,
El Paso, Texas.

Ernest A. Thiele
(former address)
25 Faber St.,
Port Richmond, N. Y.

C. A. Thomsen
(former address)
Tri-State College,
Angola, Ind.

H. C. Von Rosenberg
(former address)
713 South Ave.
Wilkinsburg, Pa.

PERSONAL

Mr. D. J. Angus who has recently become associated with the Esterline Company of Indianapolis, as treasurer, takes the responsibility of the engineering department and of the design and development of new lines of instruments and apparatus.

Mr. Angus who began his career as an engineer in the construction department of the Milwaukee Electric Railway & Light Company has since 1910 been associated with Mr. Esterline in a consulting engineer practise, embracing the design, construction and operation of power and industrial plants.

Mr. William A. Del Mar, one of the Managers of the Institute, until recently assistant electrical engineer with the Interborough Rapid Transit Company, has resigned to become chief engineer of the Electric Cable Company, and the Habirshaw Electric Cable Co., Inc., 10 East 43rd Street, New York. One of Mr. Del Mar's new activities will be the direction of the research laboratory at the Yonkers plant of the Habirshaw Electric Cable Company, where extensive investigations will be made on cables and insulating materials.

ACCESSIONS TO THE UNITED ENGINEERING SOCIETY LIBRARY

(From to November 1, December 1, 1917)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made. These are taken either from the preface or the text of the book.

All the books listed may be consulted in the United Engineering Society Library.

Acquiring Wings.

A Text on the Basic Principles Governing the Design and Operation of Modern Air Craft. By William B. Stout. N. Y., Moffat, Yard & Co., 1917. 57 pp., 11 illus., 7x5 in., cloth, 75 cts.

The original draft of this volume was written for a small corps of men from various motor car plants who were sent abroad by our Government at a certain stage in the war, to study aircraft production and its problems. Explains briefly and non-mathematically the principles of the airplane, its design, construction and operation.

An Elementary Outline of Mechanical Processes.

Giving a Brief Account of the Materials Used in Engineering Con struction and of the Essential Features

in the Methods of Producing them, also Describing Shop Processes and Equipment for the Shaping of Metals into Forms for Engineering and General Uses. Arranged for the Instruction of Midshipmen at the U. S. Naval Academy and for Students in General. By G. W. Danforth. Annapolis, The United States Naval Institute, 1917. 423 pp., 270 illus., 9x6 in., cloth.

Intended to show completely, yet briefly, the steps of metal manufacture from the ore to the finished product.

A LABORATORY MANUAL OF GENERAL CHEMISTRY.

By Horace G. Byers. N. Y., Chic., Bost., Charles Scribner's Sons, (copyright 1917) 129 pp., 49 illus., 8x5 in., cloth, $1.

A companion bock to the author's "Inorganic Chemistry".

APPLIED METHODS OF SCIENTIFIC MANAGEMENT.

By Frederic A. Parkhurst. 2d ed., N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 12+337 pp., 55 illus., 9 pl., 9x6 in., cloth, $2.

A detailed description of the application of methods, illustrated by the history of their use in the factory of the Ferracute Machine Company. The second editi n is a reprint of the first with twelve additional pages containing letters from the company mentioned, which testify to the success of the plan.

BUILDING STONES AND CLAYS.

A Handbook for Architects and Engineers. By Charles H. Richardson. (published by the author) Syracuse, The Syracuse University Book Store, 1917. 14+437 pp., 313 illus., 9x6 in., cloth, $5.50.

The object of the present volume has been to furnish an elementary knowledge of the essential minerals in building stones and the objectionable minerals they sometimes contain; to show the chief characteristics of the more important building stones; to give their geographical distribution and range in compressive strength, to impart some information as to the physical and chemical properties of clays and the products that may be manufactured from them.

References are given with each chapter and a glossary is appended to the work.

DIE FISCHWEGE AN WEHREN UND WASSERWERKEN IN DER SCHWEITZ.

Von A. Härry. Publikationen des Schweizerischen Wasserwirtschafts-Verbandes Nr. 5. Zürich und Leipzig. Rascher & Co., 1917. 115 pp., 101 illus., 12x9 in., pap., 4 franc. (gift of Schweizerischen Wasserwirtschafts-Verbandes.)

A systematic and detailed report upon the installation of fishways in water-power plants their cost and methods of construction, with a study of their value as a means of conserving the fish supply of the country. Numerous drawings and photographs of existing installations are given.

FIELD FORTIFICATION.

A Study of the Western Front in Europe 1914-1916. Reprinted from the Infantry Journal 1917. Wash., The United States Infantry Association, 1917. 106 pp., 39 illus., 10x7 in., cloth, $1.

A description of the general principles and practise of today, based on authentic information. Intended for use in educating soldiers of the United States.

GLOSSARY OF AVIATION TERMS TERMES D'AVIATION.

Compiled by Victor W. Pagé and Paul Montariol. N. Y., The Norman W. Henley Publishing Co., 1917. 94 pp., 14 pl., 8x5 in., boards, $1.

Divided into an English-French and a French-English section. Includes the terms in general use in France and America. The plates show the details of the airplane and its equipment, each part bearing its name in both languages.

HAND GRENADES.

A Handbook on Rifle and Hand Grenades. Compiled and illustrated by Major Graham M. Ainslie. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 59 pp., 23 illus., 7x5 in., cloth, $1 25.

Each type is briefly described and concise directions given for firing it. Sectional drawings show the construction. The explanations are definite and concise, and intended for persons with little knowledge of grenades.

HOW TO FLY.

(The Flyer's Manual). A Practical Course of Training in Aviation. By Captain D. Gordon E. Re Vley. Arranged by Glad Lewis. San Francisco Paul Elder and Co., 1917. 100 pp., 1 por., 6x4 in., cloth, $1.

Presents a series of graduated exercises for training aviators, intended to give the student confidence and self-reliance.

INORGANIC CHEMISTRY.

By Horace G. Byers. N. Y., Chic. and Bost., Charles Scribner's Sons, (copyright 1917). 651 pp., 138 illus., 8x5 in., cloth, $2.25.

A text-book for beginners of college grade, intended for use in classes which include those studying the subject as a complement to a liberal education and those undertaking it as a tool to be used in various professions.

INTEGRAL CALCULUS.

By H. B. Phillips. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 194 pp., 124 illus., 7x5 in., cloth, $1.25.

Contents Integration; Formulas and Methods of Integration; Definite Integrals; Simple Areas and Volumes; Other Geometrical Applications; Mechanical and Physical Applications; Approximate Methods; Double Integration; Triple Integration; Differential Equations; Supplementary Exercises, Answers, Table of Integrals, Table of Natural Logarithms, Index.

MACHINERY ENCYCLOPEDIA.

A Work of Reference Covering Practical Mathematics and Mechanics, Machine Design, Machine Construction and Operation, Electrical, Gas, Hydraulic, and Steam Power Machinery, Metallurgy, and Kindred Subjects in the Engineering Field. Compiled and Edited by Erik Oberg and Franklin D. Jones. N. Y., The Industrial Press; Lond., The Machinery Publishing Co., Ltd., 1917. 7 vol. illus., 11x8 in., ½ leather, $36.

A convenient reference library for mechanical engineers, shop foremen, draftsmen, machinists etc., giving a general survey of the mechanical field. Especial prominence is given to practise, and mathematical discussions are abbreviated when possible. The material is based on the articles published in "Machinery", but these have been supplemented by compilations from standard sources and by numerous signed articles. Contains over 3000 line illustrations. Arranged alphabetically, with frequent cross-references, and also provided with an index to subjects not brought out in the main headings. A guide to systematic reading is appended to the work.

NAVIGATION.

By Harold Jacoby. N. Y., The Macmillan Co., 1917. 11+330 pp., 22 illus., 8x5 in., cloth, $2.25.

Intended to present the methods approved by the most reliable modern authorities in a manner which can be understood by those without formal mathematical and astronomical knowledge, and yet with sufficient completeness to make possible the navigation of a ship in any ocean not very near the north and south pole without other books or tabular works, excepting only the nautical almanac for the year in which the voyage is made.

ORE MINING METHODS.

Comprising Descriptions of Methods of Support in Extraction of Ore, Detailed Descriptions of Methods of Development of Mines, of Stoping and Mining in Narrow and Wide Veins and Bedded and Massive Deposits Including Stull and Square-Set Mining, Filling and Caving Methods, Open Cut Work and a Discussion of Costs of Mining. By Walter R. Crane. 2d ed. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 13+277 pp., 84 illus., 9x6 in., cloth, $3.50.

A systematic, detailed description of methods of mining ore, illustrated by photographs of mine models, and accompanied by statements of the applications of each method, its advantages and disadvantages. Bibliographies are included with the chapters. This edition has been revised and enlarged, and a chapter on the development of mines has been added.

PRACTICAL BANKING.

By O. Howard Wolfe. Chic., La Salle Extension University, 1917. 11+290 pp., 95 illus., 8x6 in., leather, $2.

A text book for students, covering the fundamental principles but omitting those subjects which can be mastered only by experience.

PRACTICAL ELECTRICITY.

By Terrell Croft. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1917. 14+646 pp., 548 illus., 8x6 in., cloth, $2.50.

Written primarily to present the fundamental facts and theories of electricity and its applications for the use of students who desire a working knowledge of the subject, and secondarily for those who wish to review and reconstruct their concepts of electric and magnetic phenomena in accordance with modern theory and practise.

STREET RAILWAY FARES.

Their Relation to Length of Haul and Cost of Service. Report of Investigation Carried on in the Research Division of the Electrical Engineering Department of the Massachusetts Institute of Technology. By Dugald C. Jackson and David J. McGrath. Research Division

Bulletin No. 14. N. Y., McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Company, Ltd., 1917. 13+169 pp., 58 illus., 9x6 in., cloth, $2.50.

Gives the data collected and conclusions reached in a research upon the economies of the street railway industry with particular reference to the adequacy of the five cent fare under present conditions and the length of ride given for this fare.

THE TECHNIC OF SURVEYING INSTRUMENTS AND METHODS.

Including General and Detailed Instructions for Field and Office Work of Extended Students' Surveys. By Walter Loring Webb and John Charles Lounsbury Fish. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 16+319 pp., 59 illus., 7x4 in., leather, $2.

A combination of the greater part of Webb's "Engineering Instruments," a rewritten text of Fish's "Technic of Surveying Instruments," and considerable additional material. It is intended to supplement the general directions given in text-books on surveying by supplying detailed directions for specific operations in the field and office.

THE BOOK OF THE MACHINE GUN.

By Major F. V. Longstaff and A. Hilliard Atteridge. Lond., Hugh Rees, Ltd., 1917. 14+337+84 pp., 69 illus., 16 pl., 9x6 in., cloth, $3.50. (gift of Dodd, Mead & Co.)

A history and description of the evolution of the gun in its various types and of the evolution of machine gun tactics. Includes a bibliography and a list of British patents. The illustrations are arranged in chronological order and provide a graphic presentation of the progress of machine gun design and construction.

THE DEVELOPMENT OF FOREST LAW IN AMERICA.

A Historical Presentation of the Successive Enactments, by the Legislatures of the Forty-eight States of the American Union and by the Federal Congress, Directed to the Conservation and Administration of Forest Resources. By J. P. Kinney. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 18+254+21 pp., 9x6 in., cloth, $2.50.

The author has sought to confine his work to a logical presentation of the chronological development of legislation that was directed to the preservation of existing forest resources, the reforestation and extension of forest areas and the systematic management of forests for productive purposes.

THE ELEMENTS OF COAL MINING.

By Daniel Burns. Lond., Edward Arnold, 1917. 7+236 pp., 113 illus., 7x5 in., cloth, $1.10. (gift of Longmans Green & Company).

An introductory course intended specifically for schoolboys who intend to become coal miners. Gives a general idea of how coal occurs, how it is mined, how the miner is safeguarded while at work, and how coal is distributed and used.

THE ENGINEERS MANUAL.

By Ralph G. Hudson Assisted by Joseph Lipka, Howard B. Luther and Dean Peabody. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 215 pp., 227 illus., 8x5 in., cloth, $2.

This work originated from the conception that the practising engineer or engineering student would welcome a consolidation of the formulas and constants for which he is accustomed to search through several volumes and that the application of each formula might be explained more concisely than in texts devoted exclusively to the process of derivation. With this end in view those engineering formulas, mathematical operations and tables of constants which appear to be most useful are presented in systematic order and in size of book designed to fit the pocket.

Each formula is preceded by a statement in which its application, the symbology of the involved physical quantities and definite units of measurement are indicated.

THE LIGHTING ART.

Its Practise and Possibilities. By M. Luckiesh. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1917. 9+229 pp., 43 illus., 9x6 in., cloth, $2.50.

A discussion dealing with the scientific and artistic aspects of the subject, avoiding those which are commonly discussed and omitting engineering data and considerations. The author's aim is to call attention to new view-points and new possibilities in the use of artificial light.

THE TECHNICAL ANALYSIS OF BRASS.

And the Non-Ferrous Alloys. By William B. Price and Richard K. Meade. 2d ed. rev. and enl. N. Y., John Wiley and Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 9+376 pp., 25 illus., 8x5 in., cloth, $3.

A collection of accurate, quick methods intended to contain a complete treatment of the

subject in one volume and to occupy a place in the analytical laboratory corresponding to that occupied by Blairs' "Analysis of Iron". Contents: Introduction; Determination of the Metals, Some Applied Examples of Alloy Analysis; Control and Analysis of Plating Solutions.

VENTILATION LAWS IN THE UNITED STATES.

Also Board of Health Requirements and Regulations of National Board of Fire Underwriters. Together with Model Ventilation Requirements as Promulgated by the American Society of Heating and Ventilating Engineers. 3d rev. ed. N. Y., Heating and Ventilating Magazine Company, (copyright 1917). 178 pp., 3 illus., 6x5 in., cloth, $1.

Proposed Smoke Prevention Codes for large and small cities are included.

EMPLOYMENT BULLETIN

Vacancies The Institute is glad to learn of desirable vacancies from responsible sources, announcements of which will be published without charge in the BULLETIN The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Men Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

VACANCIES

V-308. Wanted: Two instructors in electrical engineering at the U. S. Naval Academy. Duties: The instruction of midshipmen in physics, elementary chemistry and electrical engineering. Salary $1800 per year. Give full information and references relating to character, education and teaching experience.

V-309. Electrical draughtsman, experienced in checking general and detail drawings on power station and substation layout work and diagrams. Permanent position; location New York City. State training, experience and salary.

V-310. Electrical draughtsman, experienced on power station and layout work. Permanent position; location New York City. State training, experience and salary.

V-311. Electrical man familiar with switchboard apparatus, capable of following through orders for central station company and checking manufacturers drawings against orders and construction drawings.

V-312. The Western Electric Company has opportunities for physicists, engineers and designers and draftsmen for work of research, development and design related to problems of telephonic, telegraphic and radio communication which are matters of public importance. Both temporary and permanent positions are open. Apply by letter, not in person unless so specifically requested, to F. B. Jewett, Chief Engineer 463 West St., New York, N. Y.

V-313. Position is open for teacher of electrical engineering in a southwestern university. A man with at least one year's practical experience is desired. Write giving experience, salary desired and qualifications.

V-314. Wanted: Wide-awake college graduate familiar with electrical apparatus, capable of solving problems in electric power transmission, mine hoisting and pumping and competent to dictate letters relative to electrical apparatus. Salary $100 per month.

V-315. Two permanent positions, $1200 per year to start, for draftsmen competent to layout and arrange equipment so as to insure efficient utilization of floor space and economical plant operation. Must have sufficient electrical knowledge to make drawings of electric light and power systems. Excellent opportunity for advancement. Location Cincinnati, Ohio.

V-316. Wanted electrical and mechanical draftsmen with experience in industrial plant layout and design. Men with technical education preferred. Salary $140-$175 per month, depending

upon the experience and ability of the man. Location eastern Pennsylvania. Give age, education, experience, nationality, minimum salary, and earliest date available.

V-317. Wanted: Man to take position as sales engineer handling motors, lamps, wiring, etc., with electric contractor in large New England city. Salary and commission. Preferably man with General Electric test experience, exempt from draft.

MEN AVAILABLE

872. Graduate electrical and mechanical engineer. Six years' experience in railway electrification work. Four years additional experience in large power development work and transmission line construction. At present in electrified railway work. Salary $2000; age 32, single.

873. Graduate electric engineer. Age 24, unmarried, not subject to draft. Three years' experience (construction, design and research) in present position. Desires to hear of an opening with broader opportunity for advancement. Minimum salary $1800.

874. Young Russian, who has served in motor service of Russian army, detailed here for inspection work by Russian Government, seeks position giving engineering experience. Studied engineering at the Sorbonne, Paris, and has had experience with automobile engines, motorcycles and inspection work. Speaks Russian, French and English.

875. Expert engineer, electric power plant experience, steam and electric phases. Age 37. Salary $7000.

876. Electrical and mechanical engineer, university graduate 1910, 32 years of age, over seven years' experience in Europe and in the United States in designing and developing power plants, magnets and solenoids. Special testing training in a-c. and d-c. machines and low current apparatus.

877. University graduate, ten years' mechanical and electrical experience, wishes to investigate opportunities in vicinity of New York City. Familiar with erection and operation for both steam and hydraulic power houses also shops, foundry and general equipment for mines. Five years connected with large projects abroad including position as resident engineer.

878. Electrical engineer, technical education, experienced on design and construction of substations, power plants, transmission and distribution systems, high and low tension equipment, supervision of city lighting plants. Have held position as chief engineer. At present employed as designing engineer. Age 25. Married. Detailed record submitted on request.

879. Experienced power station operator, load dispatcher and maintenance man. Have also had some experience in layout of switch-yards and power stations. Technical graduate. Position as office engineer desired. Available after January 1.

880. Young men (24) desires position with firm of electrical engineers or manufacturers. Technically educated. Five years drafting experience along electrical and mechanical lines. New York City only.

881. Electric railway engineer, graduate Yale University, age 29, married, desires position anywhere east of Alleghanies. Broad and thorough engineering training. Familiar with equipment of all classes of rolling stock. Absolutely dependable. Minimum salary $2700. Loyalty to present employer requires one month's notice. Reason for change present locality undesirable.

OFFICERS AND BOARD OF DIRECTORS, 1917-1918.

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(Term expires July 31, 1918)

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(Term expires July 31, 1918)
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(Term expires July 31, 1919)
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(Term expires July 31, 1918)

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DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
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C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.
JOHN J. CARTY, 1915-16.
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*Deceased.

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Revised to January 1, 1918.

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J. Franklin Stevens.

Term expires July 31, 1919.
Charles F. Brush. C. C. Chesney.
N. W. Storer,

Term expires July 31, 1920.
Carl Hering, Harris J. Ryan,
Robert Lindsay.

Term expires July 31, 1921.
W. C. L. Eglin, Bancroft Gherardi,
E. W. Rice, Jr.

Term expires July 31, 1922.
C. A. Adams, L. A. Ferguson,
S. W. Stratton.

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Term expires July 31, 1918.
L. T. Robinson, Harold Pender,
C. E. Skinner.

Term expires July 31, 1919.
B. A. Behrend, Frederick Bedell,
A. S. McAllister.

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George A. Hamilton, Treasurer,
F. L. Hutchinson, Secretary.

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Revised to January 1, 1918.

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Henry Graftio, Petrograd, Russia.

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John W. Kirkland, Johannesburg, South Africa.

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Revised to January 1, 1918.

Name and when Organized	Chairman	Secretary
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Baltimore............Dec. 16, '04	J. B. Whitehead	L.M.Potts,Industrial Bldg.,Baltimore,Md.
Boston...............Feb. 13, '03	H. M. Hope	Ira M. Cushing,84 State St.,Boston,Mass.
Chicago.....................1893	Wm. J. Crumpton	C.A.Keller,Edison Building, Chicago, Ill.
Cleveland............Sept. 27, '07	C. M. Rakestraw	C. S. Ripley, 711 Williamson Building, Cleveland, Ohio.
Denver...............May 18, '15	Norman Read	Robert B. Bonney, 806 Telephone Building, Denver, Colo.
Detroit-Ann Arbor......Jan. 13, '11	H. H. Higbie	H. J. Wyckoff, Detroit Edison Company, Detroit, Mich.
Fort Wayne...........Aug. 14, '08	J. J. Kline	R. B. Roberts, G. E. Co., Fort Wayne,Ind.
Indianapolis-Lafayette..Jan. 12, '12	H. O. Garman	E. L. Carter, Public Service Commission of Indiana,State House, Indianapolis,Ind.
Ithaca...............Oct. 15, '02	F. Bedell	Alexander Gray,CornellUniv.,Ithaca,N.Y.
Kansas City, Mo........Apr. 14, '16	W. F. Barnes	W. F. Barnes, 1012 Baltimore Ave., Kansas City, Mo.
Los Angeles...........May 19, '08	Don Morgan	A. W. Nye, University of Southern California, Los Angeles, Cal.
Lynn.................Aug. 22, '11	J. M. Davis	R. D. Thomson, General Electric Company, West Lynn, Mass.
Madison..............Jan. 8, '09	J. R. Price	L. E. A. Kelso, University of Wisconsin, Madison, Wis.
Mexico...............Dec. 13, '07		
Milwaukee............Feb. 11, '10	Arthur Simon	Soren H. Mortensen, Allis-Chalmers Mfg. Co., West Allis, Wis.
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Panama...............Oct. 10, '13	C. J. Embree	William F. Connell, Balboa Heights, C. Z.
Philadelphia..........Feb. 18, '03	Nathan Hayward	H. Mouradian, Bell Telephone Co. of Penna., Philadelphia, Pa.
Pittsburgh............Oct. 13, '02	F. E. Wynne	G. M. Baker, G. E. Co., Oliver Building, Pittsburgh, Pa.
Pittsfield.............Mar. 25, '04	F. F. Brand	E. H. Branson, General Electric Company, Pittsfield, Mass.
Portland, Ore..........May 18, '09	E. D. Searing	R. M. Boykin, North Coast Power Co., Portland, Oregon.
Rochester.............Oct. 9, '14	Frank C. Taylor	C. T. Wallis, 138 Fairview Avenue, Rochester, N. Y.
St. Louis..............Jan. 14, '03	A.McR.Harrelson	H. L. Hope, Southwestern Bell Telephone System, St. Louis, Mo.
San Francisco.........Dec. 23, '04	L. R. Jorgensen	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
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Toledo................June 3, '07	W. E. Richards	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio.
Toronto...............Sept. 30, '03	William G.Gordon	Ernest V. Pannell, 60 Front Street, West, Toronto, Ont.
Utah Section..........Mar. 9, '17	A. S. Peters	H. T. Plumb, Newhouse Bldg., Salt Lake City, Utah.
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Washington, D. C.......Apr. 9, '03	Paul G. Agnew	J. Ernest Smith, McKinley Manual Training School, Washington, D. C.

Total 33

LIST OF BRANCHES

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...bama Poly. Inst.......Nov. 10, '16	W. W. Hill	J. A. Douglas, P.O. Box 190, Auburn, Ala.
...ama, Univ. of......Dec. 11, '14	Gustav Wittig	A. F. Frazer, University, Ala.
...ansas, Univ. of......Mar. 25, '04	E. P. O'Neal	J. C. Douthit, University of Arkansas, Fayetteville, Ark.
...our Institute.......Feb. 26, '04	R. A. Newlander	A. A. Hofgren, 7542 So. Chicago Ave., Chicago, Ill.
...klyn Poly. Inst.......Jan. 14, '16	G. Hotchkiss	E. A. Demonet, The Polytechnic Institute, Brooklyn, N. Y.
...nell University.....May 17, '10	A. W. Hatfield	C. C. Gillette, Phi Gamma Delta House, Bucknell University, Lewisburg, Pa.
...rnia, Univ. of.....Feb. 9, '12	A. J. Swank	G. F. Teale, University of California, Berkeley, Cal.
...gie Inst. of Tech....May 18, '15	W. F. Eames	B. C. Dennison, Carnegie School of Technology, Pittsburgh, Pa.
...innati, Univ. of.....Apr. 10, '08	R. L. Utley	H. V. McCormick, 3110 Woodburn Ave., Cincinnati, Ohio
...kson Col. of Tech....Dec. 10, '15	R. H. Hoyt	E. S. Parks, Clarkson College of Technology, Potsdam, N. Y.
...mson AgriculturalCol. Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
...lorado State Agricultural College.........Feb. 11, '10	R. C. Richards	W. A. Stallings, Colorado State Agricultural College, Fort Collins, Colo.

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Georgia School of Technology.............. June 25, '14	R. E. Robinson	John Farago, Georgia School of Technology, Atlanta, Ga.
Highland Park College.Oct. 11, '12	E. E. Gould	Adolph Shane, Highland Park College, Des Moines, Iowa.
Idaho, Univ of.......... June 25, '14	D. Nankervis	L.J.Corbett,Univ.of Idaho,Moscow,Idaho.
Iowa State College..... Apr. 15, '03	C. L. Merrick	F. A. Robbins, Iowa St.Col., Ames, Iowa.
Iowa, Univ. of......... May 18, '09		A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col... Jan. 10, '08	L. N. Miller	M. H. Russell, Kansas State Agri. Col., Manhattan, Kansas.
Kansas Univ. of........ Mar. 18, '08	Clarence Lynn	Robert W. Warner, 1428 Tennessee Street, Lawrence, Mass.
Kentucky, State Univ. of Oct. 14, '10	A. W. Davies	G. D. Aaron,State University of Kentucky, Lexington, Ky.
Lafayette College....... Apr. 5, '12	Harry C. Hartung	William Lash Lipps, 633 Parsons, Easton, Pa.
Lehigh University...... Oct. 15, '02	R. H. Lindsay	R. D. Bean, 40 N. 7th Ave., Bethlehem, Pa.
Lewis Institute......... Nov. 8, '07	Bernard Slater	Edwin, Verrall, Lewis Institute, Chicago.
Maine Univ. of......... Dec. 26, '06	Fred P. Jones	G. K. Wadlin, Lambda Chi Alpha House, Orono, Maine.
Massachusetts Inst. of Tech................ Apr. 13, '17	Wm. H. Costello	George A. Elz, Massachusetts Institute of Tech., Cambridge, Mass.
Michigan, Univ. of...... Mar. 25, '04	W. R. Harvey	T. W. Connant, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of..... May 16, '16	Russell Ross	Ray McKibben, University of Minnesota, Minneapolis, Minn.
Missouri Univ. of...... Jan. 10, '03	A. C. Lanier	D. P. Savant, University of Missouri, Columbia, Mo.
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North Carolina Col. of Agr. and Mech. Arts.. Feb. 11, '10	John R. Hauser	Landon C. Flournoy, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
North Carolina, Univ. of.Oct. 9, '14	A. C. Forney	C. N. Sloan, Univ. of North Carolina, Chapel Hill, N. C.
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Ohio Northern Univ.... Feb. 9, '12	W. F. Parsons	A. J. Ferlic, 718 N. Main Street Ada. Ohio.
Ohio State University... Dec. 20, '02	E. S. Gunn	T. D. Robb, 124 West 10th Ave., Columbus, Ohio.
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To be presented at the Section Meeting of the American Institute of Electrical Engineers, Washington, D. C., January 18, 1918.

THE TECHNICAL STORY OF THE FREQUENCIES

BY B. G. LAMME

ABSTRACT OF PAPER

The various frequencies used in alternating-current work in America are first mentioned, and the primary reasons for their introduction are given. This covers, to a certain extent, the merits and demerits of each frequency as then understood, and the reasons each one met certain pressing commercial conditions at the time it was brought out. This is followed by a discussion of various alternating current applications which were more or less dependent upon frequency.

It is shown that there was an apparent need for two standard frequencies in the region of 60 and 25 cycles, and, further, why 60 and 25 cycles have prevailed. The special fields of application of each one are discussed fully and it is shown why 25 cycles tended to dominate the field.

The persistent developments of the designing engineers gradually overcame the limitations in various types of 60-cycle apparatus so that eventually the 60-cycle system in its application approached more and more closely to the 25-cycle and, in the end, has taken the lead.

The outcome of the battle of the frequencies was determined far more by the conditions in the operating field than by the exploitation of any particular system by designing engineers. As a consequence, the energies of the engineers were directed exclusively toward overcoming the defects and limitations of the systems and not expended in fighting each other.

THE STORY of how and why the various commercial frequencies came into use and then dropped out again, in most cases, is not primarily the story of the frequencies themselves, but of the various uses to which the alternating current has been applied.* In other words, fundamental changes in the application of alternating current have led to radical changes in the frequencies. Some of the applications which have had a determining factor on the frequency of the supply system are as follows; incandescent lighting, transformers, transmission systems, arc lighting, induction motors, synchronous converters, constructional conditions in rotating machinery, and operating conditions. A brief consideration of these items individually,

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*It should be distinctly understood that this paper covers only the story of American development.

from the present viewpoint, indicates that while some of them had, at one time, very considerable influence in determining frequency conditions, yet, in a number of cases, the original reasons have disappeared through improvements and refinements, as will be described later.

At various times the following standard frequencies have been in use in this country, namely, 133⅓, 125, 83⅓, 66 2/3, 60, 50, 40, 30 and 25 cycles per second. These did not appear chronologically in the order given above, and a few odd frequencies in a few special applications are omitted.

In the following, the various frequencies will be considered more or less in the order of their development and basic reasons will be given for their choice, and the writer will endeavor to show why certain of them have persisted, while others have dropped out. It will also be shown why the commercial situation has first tended strongly toward certain frequencies and afterwards swung toward others.

133 and 125 Cycles

In the earliest alternating work, the whole service consisted of incandescent lighting, and the electric equipment was made up of small high-speed belted single-phase generators and house-to-house distributing transformers. As the transformers were of small capacity and as their design was in a very crude state, it was believed that a relatively high frequency would best meet the transformer conditions. A choice of such an odd frequency as 133⅓ cycles per second, is due to the fact that in those early days (1886 to 1893) frequencies were usually designated in terms of alternations per minute. One of the earliest commercial generating units constructed by the Westinghouse company had a speed of 2000 rev. per min. and had eight poles. This presented a fairly convenient constructional arrangement for the surface-wound type of rotating armature, which was the only one recognized at that time. The speed of 2000 rev. per min., with eight poles, gave 16,000 alternations per minute, or 133⅓ cycles per second according to our present method of designation. Thus the earliest frequency in commercial use in this country was fixed, to a certain extent, by constructional reasons, although the house-to-house transformer problem apparently indicated the need for a relatively high frequency. The Thomson-Houston company adopted a standard frequency of 15,000 alternations per minute, (125 cycles) instead

of the Westinghouse 16,000, but the writer does not know why this difference was made. However, the two frequencies were so close together that practically they could be classified as one.

At this time, it should be borne in mind, there were no real transmission problems, no alternating-current arc lighting, no induction motors and the need for uniform rotation of the generators was not recognized. The induction motor, in its earliest stages, came in 1888 and considerable work was done on it in 1889 and 1890, but it required polyphase supply circuits and comparatively low frequency and, therefore, it had no connection whatever with the then standard single-phase, 133⅓ and 125 cycle systems. The synchronous converter was also unheard of (one might say almost undreamed of) at that time.

60 Cycles

In 1889 or 1890 it was beginning to be recognized in this country that some lower frequency than 125 and 133⅓ cycles would be desirable. Also about this time direct-coupled and engine-type alternators were being considered in Europe and it was felt that such construction would eventually come into use in America. It was appreciated that in such case, 133⅓ cycles would present very considerable difficulties compared with some much lower frequency, due to the large number of poles which would be required. For instance, an alternator direct driven by an 80-rev. per min. engine would require 200 poles to give the required frequency and such construction was looked upon as being practically prohibitive. About this time Mr. L. B. Stillwell, then with the Westinghouse company, made a very careful study of this matter of a new frequency, in connection with the possibilities of engine type generators, and after analyzing a number of cases, it appeared that 7200 alternations per minute (60 cycles per second), was about as high as would be desirable for the various engine speeds then in sight. Transformer constructions and arc lighting were also considered in this analysis. While it was deemed that a somewhat higher frequency might be better for transformers, yet a lower frequency than 60 cycles was considered as possibly better for engine type generators. A compromise between all the various conditions eventually led to 60 cycles as the best frequency. However, while this frequency originated about 1890, it did not come into use suddenly, for it was impossible to introduce such a radical change in a brief time. Moreover, the direct-coupled

or engine-type generator was slow in coming into general use and, therefore, there was not the necessity for the introduction of this low frequency in many of the equipments sold from 1890 to 1892. However, by 1893, 60 cycles became pretty firmly established and was sharing the business with the 133⅓-cycle systems. It should be borne in mind that, at this time, the adoption of this frequency was not considered as a direct means for bringing forward the polyphase induction motor, for the earlier 60-cycle systems, like the 125- and 133⅓-cycle, were all single-phase. Also, it was then thought that the polyphase motor would possibly require a still lower frequency and, moreover, the polyphase system was looked upon as in a class by itself, suitable only for induction motor work. At that time the introduction of polyphase generators for general service was not contemplated. This followed about two or three years later.

In 1890 the Westinghouse company, which had been developing the Tesla polyphase motor, laid aside the work, largely on account of there being no suitable general supply systems for this type of motor. The problem was again revived in 1892, in an experimental way, with a view to bringing out induction motor which might be applied on standard frequencies such as could be used in commercial supply circuits for lighting and other purposes. It should be understood that at this time such circuits were not in existence but were being contemplated. In 1893, after the polyphase motor had been further developed up to the point where it showed great commercial possibilities, the best means for getting it on the market were carefully considered. It was decided that the best way to promote the induction motor business was to create a demand for it on commercial alternating-current systems. This meant that, in the first place, such systems must be created. Therefore, it was decided to undertake to fill the country with polyphase generating systems, which were primarily to be used for the usual lighting service. It was thought that, with such systems available, the time would soon come when there would be a call for induction motors. In this way experience would be obtained in the construction and operation of polyphase generators and the operating public would not be unduly handicapped in the use of such generators, compared with the older single-phase types.

An early example of this new practise was in the 2000-kw. polyphase generating units used for lighting the Chicago World's Fair in 1893. Here the single-phase type still persisted, as each

generator unit was made up of two similar frames placed side by side, but with their single phase armatures displaced one-half pole pitch from each other so that the combined machine delivered two single-phase currents displaced 90 degrees from each other. It was considered that each circuit could be regulated independently for lighting service, and polyphase motors could be operated from the two circuits. These generators (at that time the largest in this country) were designed in 1892 and were of 60 cycles. These, therefore, indicate the tendency at that time toward lower frequency and polyphase generation, although commercial polyphase motors were not yet on the market.

25 CYCLES

At the same time that 60 cycles was selected as a new standard it was recognized that at some future time there would be a place for some much lower frequency, but it was not until two years later that this began to narrow down to any particular frequency. In 1892 the first Niagara electrification, after several years consideration by eminent authorities, had centered on polyphase alternating current as the most desirable system. The engineers of the promoting company had also worked out what they considered the most suitable construction of machine. This involved 5000-h. p. units at 250 revolutions per minute. Prof. George Forbes, one of the engineers of the company had furnished the electrical designs for a machine with an external rotating field and an internal stationary armature. His design used eight poles, thus giving 2000 alterations per minute, or $16\frac{2}{3}$ cycles per second. Quite independently of this, the Westinghouse company, in 1892, had been working on the development of synchronous converters, using belted 550-volt d-c. generators with two-phase collector rings added. The tests on these machines had shown the practicability of such conversion and had even proved at this early date, that the converter copper losses were much lower than in the corresponding d-c. generators. Thus it is an interesting fact that the first evidence of this important principle was obtained from a shop test rather than by calculation. The writer, from an analysis of the tests, which were made under his immediate direction, concluded that the armature copper losses must be considerably lower than in the same machine used as a d-c. generator. He also brought the matter to the attention of Mr. R. D. Mershon, then with the Westinghouse company, and the problem was then worked out mathematically by him

and the writer, in two quite different ways, but with similar results, showing that the converter did have actually very much reduced copper losses.

As a result of this work of the Westinghouse company on the synchronous converter, it was decided that, to make such machines practicable, some suitable relatively low frequency was required. This appeared to be about 30 cycles. About this time the construction of the Niagara generators was taken up with the Westinghouse company to see whether it would construct these machines according to the designs submitted by the promoting company's engineers. These designs were gone over as carefully as the knowledge of such apparatus, at that time, permitted, and many apparent defects and difficulties were pointed out. The Westinghouse company then proposed, as a substitute, a 16-pole, 250-rev. per min. machine (the speed being definitely fixed at 250 rev. per min.). This gave $33\frac{1}{3}$ cycles or as near to the Westinghouse proposed 30 cycle system, as it was possible to get. Then many arguments were brought forward, pro and con, for the two machines and frequencies. Prof. Forbes' preference for $16\frac{2}{3}$ cycles was based partly on the possibilities it presented for the construction and operation of commutator type motors, just as with direct current circuits. The Westinghouse contention was that this frequency was too low for any kind of service except possibly commutator type machines. Tests were made with incandescent lights and it was found that at $33\frac{1}{3}$ cycles there was little or no winking of light, while at $16\frac{2}{3}$ cycles, the winking was extremely bad. Tables were also made up, showing the limited number of speed combinations at $16\frac{2}{3}$ cycles for induction motors, in case such should come into use. This showed how superior the $33\frac{1}{3}$ cycles would be as regards such apparatus. It was also brought out that synchronous converters, when such became commercial, would be much better adapted for the higher frequency, as the choice of speeds would be much greater. From the present viewpoint the arguments appear to have been much in favor of the Westinghouse side of the case.

As a consequence of all this discussion the suggestion was advanced by some one, that a 12 pole, 250-revolution machine, (that is, 3000 alternations, or 25 cycles), might meet sufficiently the good qualities of both of the proposed frequencies and would thus be a good compromise. In consequence a 12-pole, 25-cycle machine was worked up by the Westinghouse company and

eventually this frequency was adopted for the Niagara generators. Afterwards, while these generators were being constructed it was brought out pretty strongly that the great advantage of this frequency would be in connection with synchronous converter operation, but that it was also extremely well adapted for slow-speed engine type generators, which were then coming into use. In consequence of the prominence given this frequency it was soon adopted as a standard low frequency, especially in those plants where synchronous converters were expected to form a prominent part of the system.

However, while 60 and 25 cycles came into use, as described above, it must be recognized that they had competitors. For instance, 66⅔ cycles (8000 alternations or one-half of 16,000) was used to a considerable extent by one of the manufacturing companies. Also 50 cycles came into use in certain plants and, to a certain extent, is still retained, but has become the standard high frequency of Europe. Instead of 25 cycles, the Westinghouse company advocated 30 cycles for some of its plants, largely because with the 25 per cent higher speeds permissible with such frequencies, the capacities of induction motors could be correspondingly increased and also incandescent lighting was more satisfactory. However, it was soon recognized that the 66⅔ and 30 cycle variations from the two leading frequencies of 60 and 25 cycles were hardly worth while, and they were gradually dropped, except in plants already installed. A brief attempt was made at a somewhat later period to place 40 cycles upon the market as a substitute for both 25 and 60 cycles. This was done under the impression that 40 cycles would give a universal system for arc and incandescent lighting, transmission, induction motors, synchronous converters and about everything else. This frequency possessed many merits and it was thought, at one time, that it might win out, but apparently the other two frequencies were too well established, and the 40 cycle system eventually lost ground.

The problem of the frequencies finally narrowed down to the two standards, and these two were accepted because it was thought that they covered such entirely different fields of service that neither of them could ever expect to cover the whole. In other words, two standards were required to cover the whole range of service. It was recognized that 25 cycles would not take care of alternating-current arc lighting and that it was questionable for incandescent lighting in general. In other ways,

LIST OF BRANCHES—Continued.

Name and when Organized	Chairman	Secretary
Colorado, Univ. of...... Dec. 16, '04	Robert Newman	William N. Gittings, University of Colorado, Boulder, Colo.
Georgia School of Technology.............. June 25, '14	R. E. Robinson	John Farago, Georgia School of Technology, Atlanta, Ga.
Highland Park College. Oct. 11, '12	E. E. Gould	Adolph Shane, Highland Park College, Des Moines, Iowa.
Idaho, Univ of.......... June 25, '14	D. Nankervis	L.J.Corbett,Univ.of Idaho,Moscow,Idaho.
Iowa State College..... Apr. 15, '03	C. L. Merrick	F. A. Robbins, Iowa St.Col., Ames, Iowa.
Iowa, Univ. of......... May 18, '09		A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col... Jan. 10, '08	L. N. Miller	M. H. Russell, Kansas State Agri. Col., Manhattan, Kansas.
Kansas Univ. of........ Mar. 18, '08	Clarence Lynn	Robert W. Warner, 1428 Tennessee Street, Lawrence, Mass.
Kentucky, State Univ. of Oct. 14, '10	A. W. Davies	G. D. Aaron, State University of Kentucky, Lexington, Ky.
Lafayette College....... Apr. 5, '12	Harry C. Hartung	William Lash Lipps, 633 Parsons, Easton, Pa.
Lehigh University...... Oct. 15, '02	R. H. Lindsay	R. D. Bean, 40 N. 7th Ave., Bethlehem, Pa.
Lewis Institute......... Nov. 8, '07	Bernard Slater	Edwin, Verrall, Lewis Institute, Chicago.
Maine Univ. of......... Dec. 26, '06	Fred P. Jones	G. K. Wadlin, Lambda Chi Alpha House, Orono, Maine.
Massachusetts Inst. of Tech................ Apr. 13, '17	Wm. H. Costello	George A. Elz, Massachusetts Institute of Tech., Cambridge, Mass.
Michigan, Univ. of...... Mar. 25, '04	W. R. Harvey	T. W. Connant, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of..... May 16, '16	Russell Ross	Ray McKibben, University of Minnesota, Minneapolis, Minn.
Missouri Univ. of...... Jan. 10, '03	A. C. Lanier	D. P. Savant, University of Missouri, Columbia, Mo.
Montana State Col...... May 21, '07	Roy C. Hagen	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of..... Apr. 10, '08	Olin J. Ferguson	Oskar E. Edison, University of Nebraska, Lincoln, Nebraska...
North Carolina Col. of Agr. and Mech. Arts.. Feb. 11, '10	John R. Hauser	Landon C. Flournoy, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
North Carolina, Univ. of. Oct. 9, '14	A. C. Forney	C. N. Sloan, Univ. of North Carolina, Chapel Hill, N. C.
North Dakota, Univ. of.. Feb. 15, '17	D. F. McConnell	Roy A. Wehe, University ,N. D.
Norwich University..... June 28, '16	Edward B. Dawson	Robin Beach, Norwich University, Northfield, Vt.
Ohio Northern Univ.... Feb. 9, '12	W. F. Parsons	A. J. Ferlic, 718 N. Main Street Ada, Ohio.
Ohio State University... Dec. 20, '02	E. S. Gunn	T. D. Robb, 124 West 10th Ave., Columbus, Ohio.
Oklahoma Agricultural and Mech. Col........... Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. Colle Stillwater, Okla.
Oklahoma, Univ. of..... Oct. 11, '12	A. W. Walter	C. H. Whitwell, University of Oklaho Norman, Okla.
Oregon Agr. Col........ Mar. 24, '08	L. Happold	Lawrence Fudge, Oregon Agri. Coll Corvallis, Ore.
Penn. State College.... Dec. 20, '02	H. A. Billig	P. J. F. Derr, State College, Pa.
Pittsburgh, Univ. of.... Feb. 26, '14	E. R. Roth	W. B. Forman, University of Pitt Pittsburgh, Pa.
Purdue University...... Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafa Indiana.
Rensselaer Poly. Inst.... Nov. 12, '09	W. J. Williams	Leroy C. Witt, Rensselaer Polyt Institute, Troy, N. Y.
Rose Polytechnic Inst.... Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Terra Haute, Ind.
Stanford Univ.......... Dec. 13, '07	H. W. Lewis	A. L. Morgan, Stanford Universit
Syracuse Univ.......... Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse Universi cuse, N. Y.
Texas, Univ. of........ Feb. 14, '08	J. W. Ramsay	J. A. Correll, Univ. of Texas, Au
Throop College of Technology.............. Oct. 14, '10	J. Paul Youtz	Clark E. Baker, Throop Dormito College of Technology, Pasade
Virginia Polytechnic Institute.............. Jan. 8, '15	Baxter McIntosh	J. A. Carr, Virginia Polytechnic Blacksburg, Va.
Virginia, Univ. of....... Feb. 9, '12	Charles Henderson	J. Arthur Evans, University, V
Wash., State Col. of..... Dec. 13, '07	S. Stites	E. Tollefson, State Coll. of W man, Wash.
Washington Univ........ Feb. 5, '04	R.W. MacDonald	Walter J. Skrainska, Washingto sity, St. Louis, Mo.
Washington, Univ. of... Dec. 13, '12	L. P. Kongsted	L. M. Lubcke, University of W Seattle, Wash.
West Virginia Univ...... Nov. 13, '14	O. P. Joliffe	D. F Cronin, 52 University Morgantown, W. Va.
Worcester Poly. Inst.... Mar. 25, '04	B. Luther	N. L. Towle, Worcester Polyte stitute, Worcester, Mass.
Yale University........ Oct. 13, '11	Brian O'Brien	G. P. Nevitt, 249 Park Street, Ne Conn.

Total 58

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THE TECHNICAL STORY OF THE FREQUENCIES

BY B. G. LAMME

ABSTRACT OF PAPER

The various frequencies used in alternating-current work in America are first mentioned, and the primary reasons for their introduction are given. This covers, to a certain extent, the merits and demerits of each frequency as then understood, and the reasons each one met certain pressing commercial conditions at the time it was brought out. This is followed by a discussion of various alternating current applications which were more or less dependent upon frequency.

It is shown that there was an apparent need for two standard frequencies in the region of 60 and 25 cycles, and, further, why 60 and 25 cycles have prevailed. The special fields of application of each one are discussed fully and it is shown why 25 cycles tended to dominate the field.

The persistent developments of the designing engineers gradually overcame the limitations in various types of 60-cycle apparatus so that eventually the 60-cycle system in its application approached more and more closely to the 25-cycle and, in the end, has taken the lead.

The outcome of the battle of the frequencies was determined far more by the conditions in the operating field than by the exploitation of any particular system by designing engineers. As a consequence, the energies of the engineers were directed exclusively toward overcoming the defects and limitations of the systems and not expended in fighting each other.

THE STORY of how and why the various commercial frequencies came into use and then dropped out again, in most cases, is not primarily the story of the frequencies themselves, but of the various uses to which the alternating current has been applied.* In other words, fundamental changes in the application of alternating current have led to radical changes in the frequencies. Some of the applications which have had a determining factor on the frequency of the supply system are as follows; incandescent lighting, transformers, transmission systems, arc lighting, induction motors, synchronous converters, constructional conditions in rotating machinery, and operating conditions. A brief consideration of these items individually,

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*It should be distinctly understood that this paper covers only the story of American development.

such as suitability for engine-type construction, application to induction motors and synchronous converters and transmission of power to long distances, it met the needs of an ideal system, as then understood. Also, in parallel operation of engine-type alternators, which was one of the serious problems of those days, the 25-cycle machines were unquestionably superior to the 60-cycle ones, due to the lesser displacement of the e. m. f. waves with respect to each other with a given angular variation in the engine speeds. However, although the 25-cycle system presented so many advantages, it could not take care of the lighting business, and, therefore, could not entirely dominate the situation.

As regards 60 cycles, it was felt that this could handle the direct lighting situation in a very satisfactory manner and was possibly better suited for transformers than 25 cycles, although there were differences of opinion in this matter, especially when it came to the larger capacities. It was reasonably well adapted for induction motors in general, but not for very low speeds. In matters of transmission and in the operation of synchronous converters it was thought to be vitally defective.

From the above consideration it would appear that the 25-cycle systems presented the stronger showing as a whole and, therefore, there was a decided tendency toward this frequency, except in those cases where lighting directly from the alternating-current system was considered of prime importance. In those systems, such as many of the Edison companies, where low-voltage three-wire direct current was used from synchronous converters, the tendency was almost solidly toward the 25-cycle system. In those days the central station, which had gotten itself committed to the 60-cycle system so deeply that it could not change, was looked upon with commiseration. Sixty-cycle plants were looked upon, to a certain extent, as a necessary evil. In fact, so strong was the tendency toward 25 cycles that in many cases 25-cycle plants were installed for industrial purposes, where 60 cycles would have been better. The 25-cycle synchronous converter development advanced by leaps and bounds and the machines were so good in their operation that it was believed that 60-cycle converters could never be really competitive with them.

On the other hand, in those large plants, which were so "unfortunate" as to have 60 cycles installed, many apparent makeshifts were adopted to meet the various service requirements.

In arc lighting, incandescent lighting, transformers and motors there was no need for makeshifts. However, in conversion to direct current, one of the greatest difficulties appeared. There were many who advocated motor-generators for this purpose, largely because the 60-cycle converter was thought to be impracticable, in spite of the fact that the manufacturing companies were putting them on the market. The 60-cycle converter at that time bore a bad name. It is now recognized that many of the faults of the early 60-cycle synchronous converter operation were not in the converters themselves, but were, to a considerable extent, in the associated apparatus. Low-speed engine-type, 60-cycle generators were not always adapted for operation of synchronous converters. In fact, in numerous cases such generators would not operate in an entirely satisfactory manner in parallel with each other, and yet when it was attempted to operate synchronous converters from these same generators the unsatisfactory results were not blamed upon the generating system but upon defects of the converters themselves. Unfortunately, defects in the generating and transmission systems usually appeared in the converters as sparking and flashing, and such troubles naturally would be credited to defects in the construction of the converters themselves. In fact, in those days, 60-cycle converters were expected to do things which now are considered as absurd. For instance, in one case in the writer's knowledge a 60-cycle synchronous converter was criticized as being a very badly designed piece of apparatus, due to serious flashing at times. Investigation developed that this converter was expected to operate on either one of two independent 60-cycle systems with no rigid frequency relation to each other. The converter in service was thrown from one system to the other indiscriminately, and sometimes it flashed in the transfer and sometimes it did not. The machine was considered to be "no good" because it would not always stand such switching.

At one time the writer stood almost alone in his belief that the 60-cycle synchronous converter presented commercial possibilities sufficient to make it a strong future contender with the 25-cycle machine, provided proper supply conditions were furnished and certain difficulties in the proportions of the converter itself were overcome. One basis for his contention was that in some of the 60-cycle plants, where the generator rotation was quite uniform, the converters were evidently much superior in their operation to other plants, using slow-speed engine-type

generators with considerable periodic variations. In such plants the hunting tendency of the converters was very greatly reduced, with consequent improvement in sparking and general operation. It was early recognized that hunting was a very harmful condition, both in 60- and 25-cycle synchronous converters, but whereas it was a relatively rare condition in 25-cycle plants it was much more common with 60 cycles. However, the operating public was not particularly concerned whether the trouble was in the generating plant or in the converters themselves, as long as such trouble existed and was not overcome. Very early in the synchronous converter development it was found that hunting would produce sparking or flashing at the commutators of the converters. However, even in those plants where there was no hunting apparent, there was difficulty at times due to flashing, especially with sudden change of load, which resulted in temporary increase in the d-c. voltage. This was a difficulty which was inherent in the converter itself and could not be blamed entirely upon the generating or transmitting conditions, for 25-cycle machines were practically free from this trouble under similar conditions of operation. Investigation developed the fact that this flashing trouble was due largely to unduly high value of the maximum volts between commutator bars. This difficulty was recognized long before it was overcome, simply because certain physical limitations in construction had to be removed. There were two ways in which the maximum volts per bar could be reduced, namely, by increasing the number of commutator bars per pole and by decreasing the ratio of the maximum volts to the average volts per bar, that is, by increasing the ratio of the pole width to the pole pitch, but both of these involved structural limitations in the allowable peripheral speeds of the commutator and the armature core. Here is where a little elementary mathematics comes in. The peripheral speed of the commutator is directly proportional to the distance between adjacent neutral points on the commutator, and the frequency. Therefore, with a given frequency the distance between the adjacent neutral points is directly proportional to the peripheral speed. Thus, a commutator speed of 4500 ft. per min. which was then considered an upper limit, the distance between adjacent neutral points on a 60-cycle converter is only $7\frac{1}{2}$ in. (19 cm.) This distance is thus fixed mathematically and is independent of the number of poles or revolutions per minute, or anything else, except the peripheral

speed and the frequency. With this distance of $7\frac{1}{2}$ in., (19 cm.), about the only choice in commutator bars per pole was 36, giving an average of $16\frac{2}{3}$ volts per bar on a 600-volt machine, and nearly 20 volts per bar with momentary increase of voltage to 700, which is not uncommon in railway service.

However, it is not this average voltage which fixes the flashing conditions, but it is the maximum voltage between bars, and this is dependent upon the average voltage and upon the ratio of the pole width to the pole pitch. Here is where one of the serious difficulties came in. As mentioned above the pole pitch is directly dependent upon the peripheral speed of the armature core and the frequency. Therefore, in a 60-cycle machine, if the peripheral speed is fixed, the pole pitch is at once fixed. For example, with an armature peripheral speed of 7200 ft. per min., which was considered high at that time, the pole pitch becomes 12 in. (30.48 cm.), regardless of any other considerations, and here was where a most serious difficulty was encountered. If a sufficiently wide neutral zone for commutation was allowed the interpolar space became so wide that there was not enough left for a good pole width. For instance, if the interpolar space was made 6 in. (15.24 cm.) wide, in order to give a sufficiently wide commutating zone to prevent sparking or flashing, due to fringing of the main field, then this left only 6 in. for the pole face. With this relatively narrow pole face the ratio of the maximum volts to the average volts was so high that with the 36 commutator bars per pole the machine was sensitive to arcing between commutator bars thus resulting in flashing. By widening the pole face this difficulty would be lessened or overcome, but with the fixed pole pitch of 12 in. (30.48 cm.) the neutral zone would be so narrowed as to make the machine sensitive to sparking and flashing at the brushes. Thus, no matter which way we turned we encountered trouble. Obviously there were two directions of improvement, namely, by increasing the number of commutator bars, thus reducing the average voltage, and by increasing the pole pitch, thus allowing relatively wider poles with a given interpolar space. These two conditions look simple and easy, but it took several years of experience to attain them. When we have reached apparent physical limitations in a given construction, especially when such limitations are based upon long experience, we have to feel our way quite slowly toward higher limitations. For instance, in the case of the 60-cycle converters we could not boldly jump our

peripheral speeds 20 to 25 per cent higher and simply assume that everything was all right. We first had to build apparatus and try it out for a year or so. Troubles, due to peripheral speed, do not always become apparent at once, and thus time tests are necessary. Therefore, while the peripheral speeds of the 60-cycle synchronous converters were actually increased 20 to 25 per cent practically in one jump, yet it took two or three years of experimentation and endurance tests before the manufacturers felt sure enough to adopt the higher speeds on a broad commercial scale. Thus, while the change from the older more sensitive type of 60-cycle converter to the later type occurred commercially within a comparatively short period, yet the actual development covered a much longer period.

Let us see now what an increase of 25 per cent in the peripheral speeds actually meant. As regards the commutator, the number of bars could be increased 25 per cent, that is, from 36 to 45 per pole, which was comparable with ordinary d-c. generator practise. In the second place, an increase of 25 per cent in the peripheral speed of the armature core meant a 15-in. (38.1-cm.) pole pitch, where 12 in. (30.8 cm.) was used before. Assuming, as before, a 6-in. (15.24-cm.) interpolar space, then the pole face itself became 9 in. (22.8 cm.) in width instead of 6 in. (15.24 cm.) or an improvement of 50 per cent. In fact, this latter improvement was so great that some manufacturers did not consider it necessary to increase the number of commutator bars, although in the Westinghouse machines both steps were made.

The above improvements so modified the 60-cycle converter that it began to approach the 25-cycle machine in its general characteristics. It was still quite expensive compared with the 25-cycle, due to the large number of poles, and its efficiency was considerably lower than its 25-cycle competitor, on account of high iron and windage losses. However, due to the need for such a machine it was gradually making headway, in spite of handicaps in cost and efficiency.

Almost coincident with the initiation of the above improvements in the 60-cycle converter, came another factor which has had much to do with the success of this type of machine. This was the advent of the turbo-generator for general service. As stated before, one of the handicaps of the 60-cycle converter was in the non-uniform rotation of the engine type generators which were common in the period from 1897 to about 1903 or 1904. But, about this latter date, the turbo-generator was making

considerable inroads on the engine-type field and within a relatively short period it so superseded the former type of unit, that it was recognized as the coming standard for large alternating power service. With the turbo-generator came uniform rotation and this at once removed one of the operating difficulties of the 60-cycle converters. However, in the early days of the turbo-generator, 25 cycles still was in the lead and many of the earlier generators were made for this frequency, especially in the larger units. But it was not long before it was recognized that 60 cycles presented considerable advantage in turbo-generator design due to the higher permissible speeds. In the earlier days of turbo-generator work, this was not recognized to any extent, as the speeds of all units were so low that the effect of any speed limitations was not yet encountered. For instance, a 1500-kw., 60-cycle turbo-generator would be made with six poles for 1200 revolutions, while a corresponding 25 cycle unit would be made with two poles for 1500 revolutions. This slightly higher speed at 25 cycles about counterbalanced the difficulties of the two-pole construction compared with the six-pole. However, before long, more experience enabled the six pole, 60-cycle machine to be replaced at 1800 revolutions, and a little later by two poles at 3600 revolutions. This, of course, turned the scales very much in the other direction. In larger units, however, the advantage still appeared to be in favor of 25 cycles, but in the course of development, 1500 revolutions was adopted quite generally for 25-cycle work, and this was the limiting speed, as such machines had only two poles, or the smallest number possible with ordinary constructions. On the other hand, for 60 cycles, 1800 revolutions was adopted quite generally for units up to almost the extreme capacities that had been considered, consequently the constructional conditions in the large machines swung in favor of 60 cycles. Therefore, with the coming of the steam turbine and the development of high-speed turbo-generator units, the tendency has been strongly toward 60 cycles. This, with the greater perfection of the 60-cycle converter, had much to do with directing the practise away from the 25 cycles.

However, there were other conditions which tended strongly toward 60 cycles. In the early development of the induction motor, the 25-cycle machines were considerably better than the 60-cycle and possibly little or no more expensive. However, as refinements in design and practise came in, certain important advantages of the 60-cycle began to crop out. For instance,

with 25 cycles there is but little choice in speed, for small and moderate size motors. At this frequency a four-pole motor has a synchronous speed of only 750. The only higher speed permissible is 1500 revolutions with two poles, and it so happens that in induction motors the two-pole construction is not materially cheaper than the four pole, consequently the principal advantage in going to 1500 revolutions was only in getting a higher speed where such was necessary for other reasons than first cost. However, in 60 cycles the case is quite different, where a four-pole machine can have a speed of 1800 revolutions, synchronous, a six pole 1200, an eight pole 900 and a ten pole 720 revolutions. In other words, there are four suitable speed combinations where a 25 cycle motor had only one. Moreover, with the advance in design it developed that these higher speed 60-cycle motors could be made with nearly as good performances as with the 25-cycle motors of same capacity, and at somewhat less cost. However, leaving out the question of cost, the wider choice of speeds alone would be enough to give the 60-cycle motor a pronounced preference for general service.

However, there is one exception to the above. Where very low-speed motors are required, such as 100 rev. per min., the 60-cycle induction motor is at a considerable disadvantage compared with 25 cycles, or this has been the case in the past. It is partly for this reason that the steel mill industry, through its electrical engineers, adopted 25 cycles as standard some ten or fifteen years ago. At that time, it was considered that in mill work, in general, there would be need for very low-speed motors in very many cases. However, due to first cost, as well as other things, there has been a tendency toward much higher speeds in steel mill work, through the use of gears and otherwise, so that part of this argument has been lost. However, there still remain certain classes of work where direct connected very low-speed induction motors are desirable and where 25 cycles would appear to have a distinct advantage.

In view of the above considerations, steel mill work has heretofore gone very largely toward 25 cycles, particularly where the mills installed their own power plants. However, in recent years there has been a pronounced tendency toward purchase of power, by steel mills, from central stations, and the previously described tendency of central stations toward 60 cycles has forced the situation somewhat in the steel mills, particularly in those cases where the central power supply company can furnish

power at more reasonable rates than the steel mill can produce in its own plant. This, therefore, has meant a tendency toward 60 cycles in steel mill work, even with the handicap of inferior low-speed induction motors. But, on the other hand, remedies have been brought forward even for this condition. The great difficulty in the construction of low-speed, 60-cycle induction motors is in the very large size and cost if constructed for normal power factors, or the very low power factor and poor performance if constructed of dimensions and costs comparable with 25 cycles. In the latter case the extra cost is not entirely eliminated because a low power factor of the primary input implies additional generating capacity, or some means for correcting power factor on the primary system. However, in some cases it is entirely practicable to correct the power factor in the motors themselves by the use of so called "phase advancers" of either the Leblanc or the Kapp type. Such phase advancers are machines connected in the secondary circuits of induction motors and so arranged as to furnish the necessary magnetizing current to the rotor or secondary instead of to the primary. In this way the primary current to the motor will represent largely energy and the power factors can be made equal to, or even much better than in, the corresponding 25-cycle motor; or, in some cases, the conditions may be carried even further so that the motor is purposely designed with a relatively poor power factor, in order to further reduce the size and cost, and the phase advancers are made correspondingly larger. In those cases where the cost of the phase advancer is relatively small compared with the main motor, there may be a considerable saving in the cost of the main motor and then adding part of the saving to the cost of the phase advancer.

One difficulty in the use of phase advancers is found in the variable speeds required in some kinds of mill work. In those cases where flywheels driven by the main motors are desirable to take up violent fluctuations in load, it is necessary to have considerable variations in the speed of the induction motor, in order to bring the stored energy of the flywheel into play. Unfortunately this variable speed in the induction motor is one of the most difficult conditions to take care of with a phase advancer, so that here is a condition where the 60-cycle motor is at a decided disadvantage.

Thus it may be seen from the above that even in the steel mill field, where the induction motor has the most extreme applications, there is quite a strong tendency toward 60 cycles, due to the purchase of power from central supply systems.

There remains one more important element which has had something to do with the tendency toward 60 cycles, namely, the transmission problem. In the earlier days of transmission of alternating current, 25 cycles was considered very superior to 60 cycles due to the better inherent voltage regulation conditions. At one time, it was thought that 60 cycles had a very limited field for transmission work. However, a number of power companies in the far west had installed 60-cycle plants, principally for local service and with the growth of these plants came the necessity for increased distance of transmission through development of water powers. At first it was thought they were badly handicapped by the frequency, but gradually the apparent disadvantages of their systems were overcome and the distances of transmission were extended until it became apparent that they could accomplish practically the same results as with 25 cycles. Part of this result has been obtained by the use of regulating synchronous condensers. It is a curious fact that the possibility of synchronous motors used as condensers for correction of disturbances on transmission systems, has been known for about 25 years, but it is only within quite recent years that they have come into general use as a solution of the transmission problem, and largely in connection with 60-cycle plants. In 1893 the writer applied for a patent on the use of synchronous motors as condensers for controlling the voltage at any point on a transmission system by means of leading or lagging currents in the condenser itself. A broad patent was obtained, but there was no particular use made of it until it had practically expired.

Another improvement came along which still further helped to advance 60 cycles to its present position, namely, the use of commutating poles in synchronous converters. The principal value of commutating poles in the 60-cycle converters, has not been so much in an improvement in commutation over the older types of machines, as in allowing a very considerable reduction in the number of poles with corresponding increase in speed, resulting in reduction in dimensions. As a direct result of this increase in speed the efficiencies of the converters have been increased. If, for instance, the speed of a given 60-cycle converter can be doubled by cutting its number of poles to one-half, while keeping the same pole pitch and the same limiting peripheral speed, then obviously the amount of iron in the armature core is practically halved and, at the same magnetic densities the iron loss is also practically halved. Also with the same

peripheral speed and half diameter of armature the windage losses can be decreased materially. Thus the two principal losses in the older converters have been very much reduced. There have also been reductions in the total watts for field excitation, and in other parts, so that, as a whole, the efficiency for a given capacity 60-cycle converter has been brought up quite close to that of the corresponding 25-cycle machine, even when the latter is equipped with commutating poles. This gain of the higher frequency compared with the lower is due to the fact that the lower-frequency machine was much more handicapped in its possibilities of speed increase, and furthermore, the iron losses and windage represented a much smaller proportion of the total losses in the low-frequency machine. This improvement in the efficiency of the 60-cycle converter together with the lower losses in the 60-cycle transformer as compared with the 25-cycle, has brought the 60-cycle equipment almost up to the 25-cycle, so that the difference at present is not of controlling importance. This development has given further impetus toward the acceptance of 60 cycles as a general system.

Formerly a serious competitor with the 60 cycle converter was the 60-cycle motor-generator. This was installed in many cases because it was considered more reliable and more flexible in operation than the synchronous converter. Both of these claims were true to a certain extent. However, with improvements in the synchronous coverter the difference in reliability practically disappeared, but there remained the difference in flexibility. In the motor-generator set, the d-c. voltage could be varied over quite a wide range, while in the older 60-cycle rotaries the d-c. voltage held a rigid relation to the alternating supply voltage. However, with the development and perfection of the synchronous booster type of converter, flexibility in voltage was obtained with relatively small increase in cost and minor loss in economy. This has been the last big step in putting the 60-cycle converter at the front as a conversion apparatus, so that today it stands as the cheapest and most economical method of converting alternating current to direct current. Moreover, while the 25-cycle synchronous converter has apparently reached about its upper limit in speed, there are still possibilities left for the 60-cycle converter.

In line with the above it is of interest to note that for units of 1000 kw. and less, the 60-cycle converter has nearly driven the 25-cycle out of business from the manufacturing standpoint.

For the very large size converters, 25 cycles still has the call, but largely in connection with many of the railway and three-wire systems, which have been installed for many years; that is, the growth of this business is in connection with existing generating systems. However, the 60-cycle converter, in large capacity units, is gaining ground rapidly and it is of interest to note that the largest converters yet built, namely, 5800 kw., are of the 60-cycle type.

One most interesting point may be brought out in connection with the above described "battle of the frequencies", namely, it was fought out in the operating field, and between conditions of service, and not between the manufacturing companies. This is a very good example of how such matters should be handled. Here the engineers of the manufacturing companies were expending their efforts to get all possible out of both frequencies, and consequently development proceeded apace. When 60-cycle frequency seemed to be overshadowed by its 25-cycle competitor, the engineers took a lesson from the latter and proceeded to overcome the shortcomings of the former. It was no innate preference of the designing engineers that has brought the higher frequency to the fore; it was the recognition that it had greater merits as a general system, if its weak points could be sufficiently strengthened; and, therefore, the engineers turned their best efforts toward accomplishing this result.

It must not be assumed, for a moment even, that because 60 cycles appears to be the future frequency in this country, that 25 cycles was a mistake. Decidedly it was not. In reality it formed a most important step toward the present high development of the electric industry. Many things we are now accomplishing with 60 cycles would possibly never have been brought to present perfection, if the success of the corresponding 25-cycle apparatus had not pointed the way. The success of the 25-cycle converter, and the high standard of operation attained, gave ground for belief that practically equal results were obtainable with 60 cycles. Therefore, the 25-cycle frequency served a vast purpose in electrical development; it was a high class pacemaker, and it isn't entirely out-distanced yet.

There has been considerable speculation as to what two standard frequencies would have met the needs of the service in the best manner, and would have resulted in the greatest development in the end. It has been claimed by some, that 50 and 25 cycles would have been better than 60 and 25. In the earlier

days possibly the former would have been better, but as a result both standards might have persisted longer. In any case, the general advantages would have been small. In one class of machines, namely, frequency changers, consisting of two alternators coupled together, the 25-50 combination would certainly have been advantageous.

Again it has been questioned whether 30 and 60 cycles would not have been a better choice. This was the original Westinghouse choice of frequencies, but not on account of frequency changers. As stated before, it was felt that 30 cycles could do about all that 25 cycles could, and would give an advantage of 25 per cent higher speed in motors and converters, with correspondingly higher capacities. Also for direct coupled alternators, the two-to-one ratio of frequencies would fit in nicely with engine speeds, in most cases. Possibly, from the present viewpoint, the choice of thirty cycles, would have longer retained the double standard.

Something further may be said regarding the 40-cycle system, brought out by the General Electric Company. This contained many very good features, for the time it was brought out. It was then believed that if the 60 cycle frequency was retained, the double standard was necessary. The 40-cycle system was an attempt to eliminate this double standard. It apparently furnished a better solution than 60 cycles then promised for the synchronous converter problem, and was a fair compromise in about everything else. But it came too late, for the 25-cycle system was too firmly entrenched, and for further development, the designing engineers preferred to expend their energies in seeing what could be accomplished with 60 cycles, as this seemed to present greater possibilities than either 25 or 40, if it could be sufficiently perfected. Thus the 40-cycle system probably missed success due to being just a little too late.

As to 50 cycles, it was stated that this is still in use to a limited extent. Most of the 50-cycle plants in this country are in California. Such plants were started during the nebulous period of the frequencies, and have persisted, to a certain extent, partly because certain 60-cycle apparatus could be easily modified to meet the 50-cycle requirements. Also, as 50 cycles is the standard in many foreign countries to which this country exports equipment, the use of 50 cycles in some home plants has not been unduly burdensome from the manufacturers' standpoint.

In addition to the preceding, there have been certain classes

of electric service which have depended upon frequency, but which have not been a determining factor in fixing any particular frequency. Among these may be considered commutating types of a-c. apparatus. The first a-c. commutating motors of any importance, which appeared, were, of course, the 25-cycle, single-phase railway motors. These as a rule have operated from their own generating plants, or from other plants through frequency-converting machinery. One exception in the railway work may be noted in the use of 15 cycles on the Visalia plant in California. There is a pretty well defined opinion among certain engineers experienced in such apparatus that some low frequency, such as 15 cycles, would present very considerable advantages in the use of single-phase railway motors in very heavy service, such as on some of the western mountain roads. Here the problem is to get the largest possible motor capacity on a given locomotive, and the main advantage of the lower frequency would be in allowing a very materially higher capacity within a given space. This does not imply reduced weight or cost compared with the 25 cycles, but simply means greater motor capacity. With the modern, more highly developed, single-phase types of railway motors, it would appear that there may be very considerable possibilities in 15 cycles.

Outside of the railway field, there has been more recently a development of various types of a-c. commutating apparatus, principally in connection with heavy steel mill electrification work. Such apparatus has been largely in the form of three phase commutating machines and these have been used principally in connection with speed control of large induction motors. As these regulating machines are usually connected in the secondary circuits of induction motors, the frequency supplied is represented by the slip frequency. Consequently where the slip frequency never rises to a large percentage of that of the primary system, such commutating motors are applicable without undue difficulties. Such motors, presumably are better adapted for 25-cycle mill equipments than for 60-cycle, but due to the tendency, already described, for steel mills to go to 60 cycles on purchased power, it has been necessary to build these three-phase commutating motors for the regulation of 60-cycle main motors, in many cases.

There is still another class of service, which has come in recently, where the choice of frequency is of much importance, but where there is no great necessity for adhering to any standard,

namely, in heavy ship propulsion by electric motors. As each ship equipment is a complete system in itself, and as it cannot tie up with other systems, there is not any controlling need for maintaining any definite frequency or voltage. Except in similar vessels, there is little chance for duplication in parts, as the various equipments vary so much in size and capacity. In consequence it has been found advisable, at least up to the present time, to design each propulsion equipment for that frequency which best suits the generator and motor speeds, taking into account the various operating conditions and limitations, such as the different running speeds, steaming radius, etc. In consequence, different maufacturers bidding on such equipments may specify different frequencies, depending upon the constructional features of their particular types of apparatus. At the present time with the relatively small amount of experience obtained with the electrical propulsion of ships, it looks as if it would be a considerable handicap to attempt to adopt some standard frequency for all service. Later, with wide experience, it may be possible to adopt some compromise frequency, which will not unduly handicap any of the service.

Conclusion

It has been the writer's intention to show that, as a rule, the choice of frequency has been a matter of most serious consideration, based upon service conditions at the time. Moreover, in view of the wide range of conditions encountered, it is surprising how few frequencies have been seriously considered in this country. Occasion has arisen, times without number, where an obvious solution of a given problem would lie in modification of the frequency to allow the use of apparatus and equipment already designed, but the engineers of the manufacturing organization have steadily held out against such policy, regardless of the apparent need of the moment. The swing of the pendulum from 60 cycles to 25 cycles and back, has covered a period of many years and, therefore, cannot be considered as a fad of the moment, but is the result of well defined tendencies, backed by the best engineering experience available. As a rule no manufacturer has made any particular frequency his "pet," but all have worked to develop each system to its utmost.

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EFFECTS OF WAR CONDITIONS ON COST AND QUALITY OF ELECTRIC SERVICE

BY LYNN S. GOODMAN AND WILLIAM B. JACKSON

ABSTRACT OF PAPER

This paper comprises a consideration of the effects of war conditions as they apply to the electric light and power service of the country, but the principles enunciated relate in their broad application to all kinds of public utility service.

The electric companies are facing a grave situation owing to the Government's needs and requirements, to the abnormal prices of labor, supplies and equipment, to the difficulty of retaining their trained employees, and to the present impossibility of satisfactorily financing extensions.

Owing to these conditions the electric companies may be forced to regularly operate their systems, during the continuance of such conditions, with reduced reserve in capacity of equipment and with partially trained operating forces, with accompanying reduction in efficiency of operation and reliability of service as compared with normal conditions.

It is shown that the increased cost for fuel and other supplies, labor and taxes alone, occasioned by the war conditions, would amount to an increase of more than $116,000,000 over the operating expenses that should have been expected for the electric light and power companies of the country under normal conditions for 1917.

The important advantages which are inherent in the central electric power stations for supplying power for war manufactures and the advisability for the government to make every reasonable endeavor to encourage the development of the central electric stations is pointed out.

To work out the situation to the best interests of the public and the companies will require earnest cooperation between the Government and the companies. Although the situation is one requiring the determination of how the electric companies can best meet the power requirements for war manufactures, yet the way in which the problems involved are worked out will have a bearing upon the cost of electric light and power service not only during the war but for long after its termination.

THE EFFECTS of war conditions in the public utility field are demanding at the present time the most careful consideration of both the operating and the regulatory bodies throughout the country. We have had a preliminary course of training, as it were, both in the experience of our foreign contemporaries

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and in our own experience prior to and during the entry of the UnitedStatesinto the war. But there is a wide difference between the effect on the electric utility field of this country, with the nation in the status of a neutral with its industries independently meeting the demands of the domestic and foreign markets, compared with the conditions produced by the United States standing as a growing war power, collecting, directing and conserving its vast resources for the prosecution of the conflict.

War conditions are extraordinarily affecting every department of production and distribution of electrical power, and the results not only have to do with the present and immediate future, but the effects are likely to extend far beyond the termination of the war. How far these effects will reach into the future will depend not only upon the length of the war, but to a large extent upon their treatment during its progress, and how resolutely the situation is now faced by engineers, bankers, and government officials. It is therefore important for us to analyze these influences.

This paper deals more particularly with the effect of war conditions upon electric light and power service, but the principles relate in their broad application to every kind of public utility service.

The principal directions in which the effects of war conditions on electric service appear are:

1. In relation to operating:
   (a) In inceased salaries and wages paid for operating.
   (b) In difficulty of retaining trained operatives, and conversely the need to operate with partially trained forces.
   (c) In increased cost and difficulty of obtaining fuel and in reduction of its uniformity and quality.
   (d) In increased cost of other supplies and materials for operation and maintenance.
   (e) In the need for protecting the properties against enemy agents.
   (f) In increased taxes.
   (g) In possible decrease of consumption of electric power by ordinary customers.
   (h) In possible changes of load factor.
2. In relation to extensions of plant:
   (a) In the necessity in many cases for quickly caring for large accessions of permanent and temporary business.
   (b) In increased cost over normal for plant required to care for additional business.

(c) In high cost for money and difficulty of obtaining it at any rate considered reasonable in normal times.

(d) In the difficulty of obtaining equipment in reasonable times of delivery.

Each one of the above factors has a direct bearing upon the cost and quality of electric service and any one of them arising under normal conditions would demand careful consideration and treatment, but when all of these factors arise coincidently and are affecting an industry which has been operating under circumstances requiring for stability and success the condition of steady and predictable markets for its purchases and sales, the results may be not only serious but even destructive if the appropriate measures of relief cannot be obtained.

The effects of the war conditions are being manifested not only in the matter of heavy increases in operating costs but also in the matter of extraordinary increases in cost for new plant required to care for added business. At first thought it might be concluded that the former apply only to the period of the war, but increases in wages for any cause usually result in all or a part of the increases remaining after the cause has been removed, also temporary changes in operating methods are likely to bring about modifications in the permanent methods of operation. The latter may increase the cost per unit of output incident to investment in plant, and therefore affect the cost of service not only for the period of the war but for the life of such plant, unless the increases in plant investment over normal can be amortized through increase in revenue during the period of the war and the period of readjustment which must succeed the war.

The effects of the war conditions have already increased the operating expenses of the electric companies of this country to the extent of over a hundred and sixteen million dollars per year, as hereafter shown. This points to the necessity of readjustment to the new conditions without delay, while at the same time requiring readjustment to abnormal labor conditions.

Any complete study of the effect of the increase in expense for operating wages and salaries on the operations of electric companies, caused by war conditions, is a difficult proceeding because every class of labor is represented, from the unskilled wage worker to the highest class of administrative official, and increases among these classes differ in their proportions, the highest paid men having received the smallest proportional increases, if any;

also because the wages paid for the same kind of labor as well as the increases involved vary throughout the country. Moreover, the growth of companies and accompanying increase in output per unit of labor, improvement in organization and in the science of economic labor application have tended to continually reduce the cost of labor required per unit of output, that would otherwise be required to produce equal or improved results. Although individual salaries and wages have been gradually increasing during past years, the labor cost per unit of service had been decreasing prior to the war. War conditions, however, have greatly affected this situation. The growing scarcity of labor in the ordinary occupations of peace, due to stoppage of immigration, demands for industrial workers for government work and drafts for the National Service, together with the necessity for enabling employees to meet the increased cost of living and the competition for retaining some experienced employees and of obtaining new employees, all combine to increase wage and salary scales. The employment of women has enabled the electric utilities to obtain an additional class of labor at a relatively low rate, but when women take the places of men, more women employees are required than the number of men replaced, and the war conditions tend to exhaust the supply of even this class of labor by offering wider fields of employment. The necessity for female labor to become more nearly self-supporting during war-times further tends to increase the female wage scale.

It is recognized that the labor cost to public utilities will further advance either by increases in the direct wage or by some system of war additions such as are being employed by the other nations at war. This system of war additions is generally recognized as a measure to compensate for the temporary increases in living costs during the war period and is adopted principally in order to facilitate the ultimate return to normal conditions.

It should be recognized that by normal labor conditions for the future, we do not mean the identical conditions existing prior to the war, but refer to the conditions which would normally have been attained had war conditions not intervened.

An analysis of the United States Census statistics shows that the increase in the average wages paid per employee (exclusive of general officers, managers and superintendents) during the ten years from 1902 to 1912 was 11 per cent. The actual increase in wages for like classes of labor may have differed from this figure,

since the evolution of electric generation and distribution apparatus has shifted the relation of unskilled and skilled employees, but it plainly shows how abnormal are the sudden great increases in wages which have occurred as a consequence of the war.

During the war period thus far, salaries of officers, managers and general superintendents have in general not greatly increased but increases in wages in the operating departments have ranged from 15 to 50 per cent and we are of the opinion that 25 per cent may be taken as the average increase thus far occasioned by the war.

The total salaries and wages paid to employees of electric companies throughout the United States make up about one-third of the total operating expense, including under the latter heading the cost of power purchased and the renewals and replacement expenses, but not interest on capital debt. Under normal growth from 1912, at the rate indicated by the growth during the previous ten years we find that the salary and wage disbursements of electric companies in the year 1917, had there been no unusual disturbance, should have amounted to $90,000,000 of which one-seventh would have been for general officers, managers and superintendents' salaries and six-sevenths for wages.

From this it is seen that the increase in wages of 25 per cent means an outlay on the part of the electric companies of $19,000,000 for the year.

In the matter of retaining trained operatives, the government's draft for war services and the war scale wages offered in industrial fields both contribute to deplete the trained operating forces of the electric companies. We believe the government will and should, as a matter of good business, not unduly hamper the carrying on of a service so essential to its needs, but many of the finest electrical employees have voluntarily enlisted and the draft has taken a share of trained employees. Also, although the permanent employment in the public utility field tends to make it in that aspect more attractive than more or less temporary employment of war industries, yet many of the best employees of the electric companies have not been able to withstand the temptation of the higher wages obtainable in the latter, associated with the idea of being closer to war activities.

This situation is already being felt not only in increased wage scales, but also in cost for training new operatives, and the continual change in employees will necessarily be reflected in a re-

duction in economy of operation and in some reduction in the quality of service not only in the supplying of power but also in the accounting departments, and in the new business departments as far as they are maintained. The effects of this condition will become more and more apparent as time progresses, and the utilities must be prepared to meet the conditions of depleted forces and untrained operatives. We are unable to estimate the effects of this condition in terms of dollars and cents, but it is evident that it is a condition that will require no small consideration on the part of those responsible for the operation and service of the public utilities.

The electric utilities meet the largest single item of increased expense in the fuel account. The gross cost of fuel of a given quality is made up of cost at the mine, cost of transportation, and cost of labor for handling; and, due to differences in mining costs, length of haul and purchasing facilities on the part of the utilities, the gross costs as well as the increases have differed materially among the utilities, and throughout the country. In addition to tremendous increases in costs per ton, the utilities are confronted with the necessity of accepting coal of inferior and non-uniform quality, which results not only in lower efficiency due to reduction in heating value but also in lower efficiency incident to operating boiler equipments with continually changing grades of fuel. These conditions are now being keenly felt in the more modern highly efficient steam generating plants.

The cost of fuel has an extremely important bearing upon the total cost of electric service. Estimates based upon the United States Census reports show that this item of expense for all the electric companies in the United States would have reached $50,000,000 for the year 1917 under normal conditions of the country, and would have amounted to about 60 to 65 per cent of the normal generating expense. Definite information as to the amount of increase in fuel cost for the whole country is not available, but from information obtained from various sections of the country, we arrive at the conclusion that on the average the cost per ton of coal to electric companies has increased a little more than 100 per cent on account of war conditions, and that 100 per cent is not far from correct. On this basis the increase of total cost due to the increased price per ton of fuel is $50,000,000. A conservative figure for the increase in tonnage due to lower quality and non-uniformity of grade is 10 per cent, which means an added increase of $10,000,000, making the total increase $60,000,000.

Reliability of service has already been adversely affected in some instances by the fuel situation, and the importance of maintaining continuous service especially in congested territory and in industrial centers producing war materials is obvious. The size of the reserve coal supply required to assure continuity of service is dependent upon the rate of use and the dependability, frequency and regularity of deliveries. Present conditions of coal production and transportation point to the need for more than normal reserve coal supply and its importance we believe fully justifies the abnormal expenditures which have been necessary in the purchase of coal for the purpose of maintaining the supply.

An estimate of the output from steam driven electric central stations which might have been expected for 1917 under normal conditions shows 13,000,000,000 kw-hr., and an average requirement of three pounds of coal per kw-hr. of output, shows the fuel requirements would amount to not over 20,000,000 net tons, which is approximately 3 per cent of the estimated output from the mines for 1917. It is thus seen that a relatively large reserve supply of coal in the hands of every electric company would tie up but a very small part of the coal supply of the country and this supply would be widely distributed over the country and to a certain extent would be in proportion to the populations and industrial importance of the several sections of the country.

The normal cost of materials and supplies other than fuel, used in operation and current maintenance of electric properties, makes up no small proportion of the total annual operating expense, which we estimate as a little over 15 per cent. The percentage increases in the cost of such materials and supplies due to war conditions have been enormous and extremely varied in amount and the determination of the average amount of these increases imposed on electric companies is very complicated, but the indications are that this amounts to as much as 75 per cent. Such an increase in this expense means an increase in expenditures in the neighborhood of $30,000,000 over normal expense for 1917.

The increase in the cost of materials and supplies may be expected to cause operating companies to curtail their repairs and current maintenance to the greatest possible extent but such reduction cannot be large if satisfactory quality of service is to be maintained. In the matter of supplies contemplated for improvements and replacements of plant, however, the difficulty in obtaining equipment in reasonable times of delivery and the

abnormal cost of any equipment that may be required naturally points to the advisability, and in many cases the necessity, of retaining present equipment in service until the exigencies of the situation make a change imperative, even though under normal conditions it would be advantageous to make the changes promptly, thus introducing an element of reduced economy in operation which under normal conditions would not be present.

The measures which must be taken to protect property from malicious interference by enemy agents comprise the development and maintenance of effective protective structures and lighting systems as well as special policing. The large capacity of individual units of generating equipment and the large capacity of transmission circuits of today increase the necessity for thorough protection owing to the large amount of damage that could be accomplished by an enemy agent if given the opportunity. The government action in restricting the activities of the enemy alien population is an important safeguard in this connection but the necessity for direct protective measures during the continuance of the war adds hundreds of thousands of dollars to the normal expense accounts of individual large electric corporations and runs into the millions in the total cost of service throughout the country. How many millions of dollars it amounts to we are not prepared at this time to say, but we expect the aggregate amounts to at least two or three million dollars.

In the matter of increased taxes we have purely a problem of caring for the increases over those of times prior to the war, and there is no way of predicting how large a factor this expense will become during the progress of the war or how far it will reach into the future. Estimates based upon the United States Census returns indicate that the 1917 taxes paid by electric companies might normally have reached $25,000,000. The proportion of gross revenue required for taxes has apparently been increasing year by year, having been slightly over three per cent in 1902, a little over three and one-half per cent in 1907, and nearly four and one-half per cent in 1912. Taxes on net income made up a very small proportion of the total tax in former years, so that changes in net income had little bearing on the amount of the taxes. This form of income taxation has had growing favor in legislative circles and is freely used by the government in its war tax program. An estimate of the amount of the expense which may be expected to be added to the cost of electric service

throughout the country by the operation of the net income tax law is obviously dependent upon the effect of war conditions on net incomes, and the effects of "tax free" bond clauses and taxes on Excess and Undistributed Profits clearly cannot be estimated. We may hazard a guess that the increase over normal expense will lie between $5,000,000 and $10,000,000 for the year 1917.

Summing up the foregoing amounts shows that the extra expenses now imposed on the electric companies on account of war conditions amounts to the immense aggregate per year, as follows:

Increased salaries and wages chargeable to operating.	$19,000,000
Increased cost of fuel...........................	60,000,000
Increased cost of other materials and supplies.......	30,000,000
Increased taxes..................................	7,500,000
	$116,500,000

This amounts to a quarter of the normal estimated gross revenue for 1917 of all the electric companies and it wipes out two-thirds of the sum that would have been available for interest, dividends and surplus. It does not include additional expenses caused by the difficulty of retaining trained operatives and the cost of protecting the properties against malicious interference, the magnitude of which we are unable to estimate. It puts the electric companies in a critical position, which is rendered more ominous by the impossibility of foretelling how much larger these extra expenses may become in future months.

It is to be expected that the American people will come to more fully appreciate the need for economies in every direction as the war progresses, and that their consumption of electric power for residential and ordinary commercial lighting will become materially reduced. This effect is now just beginning to be felt by the electric companies. It can result in only a relatively small reduction in the outputs of the electric companies but to that extent it will liberate generating capacity for use in war service and will conserve some fuel. It will, however, liberate relatively little distribution plant which can be used for war demands and will have substantially no effect upon total distribution expenses, so that a very large part of the reduction in gross revenue arising from such economies will appear as a reduction in the net income. As an economic consideration of the

war such economies are to be earnestly encouraged, but it is nevertheless true that so far as the electric companies are concerned they mean reduction in net income almost equal to the amounts by which the gross revenues are affected. It is not possible to estimate what the effect on the companies' revenues will be except to say that it apparently will run into the millions.

Before considering further the operating phases of the situation we will take up the effect of war conditions on extensions of plant since the two phases are so closely interrelated.

The effects of the war conditions are being manifested not only in the matter of heavy increases in the operating costs already pointed out, but also in the matter of extraordinary increases in cost for new plant required to care for added business. At first thought it might be concluded that the effects of the latter apply only to the period of the war, but the increased cost of new plant per unit of capacity manifestly affects the cost of service not only for the period of the war but for the life of such plant, unless some measures can be devised to amortize the excess first cost of new plant over the first cost of like plant in normal times.

Many electric companies are now confronted with the necessity of not only caring for their normal growth of business, but have had thrown upon them large demands for power arising from the increasing expansion in the manufacture of material of war, which includes almost every necessity of life, ranging from shipping to textiles and food stuffs, in addition to special war products like arms and ammunition. On this account the electric companies have found themselves obliged to prepare very rapidly to meet increased power demands of several hundred thousand horse power over their normal requirements.

When viewed from every standpoint, it will be seen that the economical central power generating station is the proper medium for the supply of the large power requirements arising on account of the war, since purchased power leaves the manufacturers of munitions and other war material free to devote their energies to the development and operation of their manufacturing plants without diverting any of their energies to the development of power plants or their operation; it provides the greatest possible amount of available power from a pound of fuel; it reduces the total capacity of power generating equipment necessary by taking advantage of the diversity between the power requirements of the various manufacturing establish-

ments; and it provides the greatest possible amount of available power per man occupied in the power generation field and thus diverts the least possible man power from the other needs of the nation. It also makes it possible for the power equipment manufacturers to concentrate upon the production of the larger units of equipment used by central electric stations, thereby making it possible to produce the largest capacity of equipment in the least time. And the centralization of electric power generation equipment, with comprehensive distribution systems, places it in position to most effectively care for the changes in power requirements of industrial establishments to be expected after the termination of the war.

These advantages of the central station power are so large that it is advisable for the Government to use every reasonable means to encourage the central station companies and discourage individual power plants during the war period.

It is to be expected that much of the business arising from the war will prove of a temporary character, so that the electric companies are faced with the double dilemma of finding themselves called upon to provide capacity to care for extraordinary accessions of new business, at costs for the equipment and installation far above normal prices, and this in the face of the fact that it is to be expected that in many cases some of the business will prove of temporary nature without equivalent other demands to take its place after the war.

The electric companies have so far provided for the needs of the situation splendidly, but this has been done largely at the expense of reserve capacity, as the financing of almost no large extensions, if any, has been accomplished since our country become a party in the war. There can be no doubt that the power demands on account of the war have not yet nearly reached their maximum and it will be necessary to devise some way by which it will be possible to care for these demands. This can be accomplished by the adoption and promulgation by the government of certain war measures; one being to make possible the discontinuance or curtailment when advisable particularly at the peak load periods of the electric companies, of power and lighting demands not necessary for prosecution of the war or for the safety and reasonable necessities of the population, and another being for the government to assume the responsibility for seeing that money for extensions required for war service can be obtained on reasonable terms.

The first named measure would also operate in the interests of fuel conservation.

We may show the effect of war prices on the electric light and power business in the aggregate. The United States Census of central stations shows that the total of the revenues received from operation and other sources by all central electric light and power systems (including both hydraulic stations and steam stations) in 1912 was in round figures $302,000,000 and the total operating expenses, including taxes, and renewals and replacement expense, but not including interest on debt, was $184,500,000, leaving a total income of $117,500,000. The reported cost of construction and equipment was $2,176,000,000. Extension of these totals to the present year 1917 shows that under normal growth the total revenues in 1917 would have reached $475,000,000 and the operating expenses, including taxes and renewals and replacement expense would have reached $290,000,000 making the total income before deducting interest on debt, $185,000,000. Estimating the reported cost for construction and equipment would have grown to $3,500,000,000, an increase of 60 per cent in five years, the above income would represent 5.3 per cent of this cost of construction and equipment. If no other factors entered into the problem besides increases in cost of operation, and assuming these increases effective over the whole year, the fuel expense as before pointed out, would increase $60,000,000 for 1917, other supplies $30,000,000, labor expense $19,000,000 and taxes $7,500,000, representing an aggregate increase of operating expenses for these items of $116,500,000. This is an increase of 40 per cent in operating expenses, and it reduces the divisible income to $68,500,000, which amount is equivalent to less than 2 per cent on the cost of construction and equipment. This percentage is still lower in the case of the steam-electric systems of the country taken alone, and additional expenses for training new employees and the lowered efficiency of such employees, the cost of special policing, etc., reduce the amount still farther.

There are certain operating economies and changes which might be adopted by the companies if forced to it by war conditions. The service rendered the customers might be curtailed for example by discontinuance of lamp deliveries and free minor repairs, by less prompt attention to troubles and complaints, thereby reducing the number of "trouble" employees, by bimonthly or tri-monthly billing and the like; the canvassing and

promotion departments might be almost entirely dispensed with, with consequent reduction in meter testing and setting expense; and advertising expense might be eliminated. In the storeroom, increased cost for material points to more than merely salvaging scrap material. It forces the use of old and shopworn supplies and non-standard equipment, and previously used wire and cables. While the use of such equipment may render the service less reliable, it may become an unfortunate necessity.

The current expense accounts may also be reduced by postponement of plant repairs which would normally be made at once; but it is well recognized that the longer repairs are put off the more they cost, and while current expenses may for a time appear lower, the cost in the long run is apt to be increased.

The net results of such economies might amount to as much as 10 to 15 per cent of the normal operating revenue of the electric companies, and every consideration should be given to them, but they are offset by increases in expense which have not been included in the amounts named.

There is a phase of the situation which has not been referred to in the preceding but which in some cases is already being felt, and is likely to be generally felt by electric companies. This is the improvement in load factors arising from putting the less essential industries on an off peak basis and the fact that war industries give an exceptionally long hour demand, owing to the intensive character of war manufacture. This produces two quite distinct results, one being in the direction of reducing the maximum loads which may be carried, particularly on underground cables and to some extent upon generating equipment, and the other being in the direction of decreasing the expense, other things being equal, per kilowatt-hour of total output. How much effect the first result may have it is impossible to predict but it may have marked effect in cases where the load factors become very high, and it is already showing.

A part of the increased cost on account of war conditions has been provided for by many companies by the introduction of coal clauses in contracts for large light and power service. These clauses have taken various forms from the simplest in which the increased (or diminished) charge is figured at a given amount for each dollar of change from a stated cost of coal per ton, to the more elaborate form in which the increased charge is figured upon the relation between the present day cost and

the cost in a prior period for the coal required for performing the same amount of work.

But even if coal clauses could be satisfactorily applied to all electric rates, which they cannot, they would be only a partial remedy for the present conditions since the increase in cost for coal is only about one-half of the total increase in cost due to the war conditions. Each electric rate requires modification to take into account the other factors as well as coal entering into the cost, so as to increase the total revenue approximately 25 per cent, in order to bring the same income to the electric companies of the country to cover interest and surplus as would have been expected for 1917 under normal conditions. It should be noted, however, that a correctly adjusted coal clause more fully meets the situation for contracts with high tension customers than with the general average of small customers in serving which there are large expenses for labor and materials required in the processes of transformation and distribution.

What has been pointed out in the foregoing regarding the effect of war conditions on central station electric service is also applicable to the cost of power produced by private power plants. The immensity of this field is seen by reference to the United States Census of Manufacturers for 1914, in which the total primary power reported as used in this field aggregated 22,500,000 horse power (exclusive of isolated electric plants for office buildings, hotels, etc.) of which 15,700,000 horse power was comprised of steam driven equipment and only 3,900,000 horse power was in the form of purchased electric power. The central station steam and water-driven electric generating capacity in 1912 was only 7,500,000 horse power, with a probable 9,000,000 horse power in 1914.

The high costs and difficulty of obtaining new equipment and operating supplies, produced by war conditions, and the increased demands on the industries, draw the manufacturer to the central station for either his whole or additional supply of power. Here is a fertile field for conservation of fuel, through the supply of this power by central electric companies but it is evident that under present conditions the electric companies cannot afford to add such load except at fully compensatory rates based on war costs, and on long term contracts, and that they are practically barred from undertaking such service owing to the financial situation, except where the cost of additions of equipment has already been financed.

In the extension of the central station into this field and especially in the acceptance of temporary or auxiliary loads, there is the menace to the central utility of being burdened with unused and abnormally expensive station capacity at the end of the war period. This menace lies not only in the possible decrease of manufacturing activity but also in the possibility that the user may return to private plant operation with the re-establishment of normal markets. It would seem unfair that the future inhabitants of an industrial territory who had been called upon to furnish large amounts of war material for defense of the whole country should alone bear this burden of unused capital. A more equitable distribution of the burden might, for example, lie in special rates for such service, long-term contracts, or in capital subscriptions or deposits made by the power users to carry the investment until such time as the plant not used after the war period is put into active operation again.

Considering the output of power by the industrial plants using steam power, which do not now purchase electric current, estimated on the basis of the capacity of equpment as reported for 1914, operating at the equivalent of full load for a sixth of the time, the total horse power output would amount to 23,000,000,000 h.p -hr. It is safe to say that at least three-quarters of this is such that the exhaust steam cannot be effectively used for heating purposes and there would be a possible saving of at least 1½ pounds of coal per horse power hour through service of this three-quarters from central steam-driven electric stations, making a total saving in fuel of 13,000,000 tons of coal per year under the industrial plant output for the year 1914. The saving would be much greater when considering only the more modern and economical central stations. The same considerations as above apply to the field of isolated building and hotel electric plants where conservation of coal amounting to millions of tons could unquestionably be effected.

We have heretofore given principal consideration to the effect of war conditions as increasing the demands for service. We have not as yet in this country much experienced the opposite effects of economies forced by war conditions. In England, the danger from air raids and the necessity for conserving coal have materially decreased and in some cases almost wiped out the street lighting service furnished by many companies, and government regulations together with economies practised by the customers have very materially reduced the domestic and commercial lighting loads. It is obvious that such losses of business

coupled with increased cost for supplies and labor increase the expense per unit of output far beyond the point where it may be neutralized by any economic practises of the supplying company. The result has been quite a universal increase in rates, in some cases flat percentage increases of the same amount for light and power, in other cases differing percentage increases for light and power, and in still others increases depending upon changes in cost of fuel. These flat percentage increases have varied from less than 10 per cent to as high as 50 per cent over the rates in effect prior to the war, London rates having been increased 50 per cent according to the London *Electrical Review.*

As to the effect of war conditions in this country on ordinary domestic and commercial light and small power consumption for other than manufacturing purposes, the rate of adding new residence and commercial customers is on the whole falling off due to personal economies of the public and generally fewer extensions of lines by the companies, and to decrease in building activities, and the like. It does not appear that the lighting customers in this country have as yet inaugurated any general lighting economies sufficient to be seriously felt by the companies, and the companies have on the other hand shown a disinclination to increase the rates to small consumers. The drain on our resources will, however, be felt more and more as the war progresses, and it is to be expected that the domestic and commercial customers will decrease their consumption of current.

Government action toward conservation of our resources during the war may result in the adoption of plans such as the "Day Light Saving Plan" now in considerable use in Europe. The effect of such action on the cost of electric service is substantially the same as results from voluntary economy practises, in that the use of current is reduced without full equivalent reductions in expense for generating and distributing plant required or in the expenses connected with operation. While some forms of rates in common use are designed to return, first, as much as practicable of those costs of service not dependent upon the quantity of current used, commercially applicable rates cannot be so nicely balanced as to make the appropriate returns under all conditions. It is obvious that any action directed toward general lighting economy, while conserving our national resources and possibly releasing some plant for uses more essential to carrying on the war, results in higher relative cost per kilowatt-hour of current furnished and this points toward higher rates to the public.

It is evident that increased expense for service arises in every department of the business; in operating labor and supplies and taxes, in protection of the property, and in cost for extensions of plant. And the latter is not only affected by abnormal first cost for equipment and its installation but also by the present difficulty of obtaining money for such purposes at other than exorbitant rates as compared with normal. In the matter of labor expense the cost of service is increased not only on account of increase in wages but by the need for training new employees to the service and the necessity of operating with partially trained employees. These last conditions are likely to be increasingly felt with each new draft of men for the armed forces or other direct government service. The increases in cost of electric service on account of the war conditions are so great that rates for service which were equitable at the beginning of the war, are in some cases now not covering the operating expense, and where companies are being loaded with war business the new business in many cases may become a serious menace to the company, which can only be overcome by taking into account the war conditions in determining the rates to be charged.

Notwithstanding that wages of operating men are higher than ever before, yet the necessity for using many partially trained men in the operation and inspection of electrical systems makes for a lowering of reliability of service and this coupled with the need in some cases to utilize all equipment to its limit with reduced reserve capacity has a further effect in this direction as well as in the direction of reduced operating efficiency. Also it is to be expected that with present conditions added transmission lines will not be installed if the present circuits can possibly carry the loads, even though under ordinary conditions additional circuits would be promptly provided, and like considerations apply to distribution systems with a consequent tendency toward reduced efficiency and a wider range of voltage variations than is now considered good practise. It seems proper that regulatory bodies should take into account these considerations in their requirements for electric service during the period of the war.

It should be recognized that the electric companies while serving the best interests of the public broadly may in some cases be obliged to operate with impaired forces and to utilize their equipment during the war to such an extent that they may be unable to fully maintain present standards of service.

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OF THE

AMERICAN INSTITUTE

OF

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Vol. XXXVII Number 2

FEBRUARY, 1918

Midwinter Convention, New York, February 15-16, 1918
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MIDWINTER CONVENTION

New York, February 15-16, 1918

MEETING IN CLEVELAND

March 8, 1918

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OF THE

American Institute of Electrical Engineers

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GEORGE R. METCALFE, Editor.

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PROCEEDINGS

Vol. XXXVII | FEBRUARY, 1918 | Number 2

A. I. E. E. MIDWINTER CONVENTION

The Sixth Annual Midwinter Convention of the American Institute of Electrical Engineers will be held February 15 and 16 in the Engineering Societies Building, New York.

On account of war conditions the Meetings and Papers Committee, with the approval of the Board of Directors, has decided to make this convention purely a business meeting and therefore no entertainment features or excursions have been included in the program.

The convention will include four technical sessions which will take place on Friday morning, Friday afternoon, Friday evening and Saturday morning. A strictly informal dinner will be held between the afternoon and evening sessions on Friday.

The session on Friday morning will be devoted to the subject of Circuit Breaker Ratings. That on Friday afternoon to Meters and Measurements. The Friday evening session will be devoted to a lecture by Dr. A. C. Crehore, followed by discussion. This session will be of general interest to everyone, as the subject will be presented in a popular and non-technical manner. The session on Saturday morning will be devoted to the subject of "Alternating-Current Commutator Motors."

The regular monthly meeting of the Board of Directors will be held Thursday evening at 8:00 p.m. at Institute headquarters. Other committee meetings will be held on Thursday as specified in notices to committee members.

The Registration Bureau will be at the entrance to the meeting rooms. Morning and afternoon technical sessions will be held in the Assembly Room on the fifth floor and the evening session will be held in the Auditorium on the third floor.

PROGRAM

All the following papers are printed in this issue of the PROCEEDINGS. Separate reprints will be distributed at the technical sessions.

Friday, February 15

10:30 A.M.

Opening remarks by President E. W. Rice, Jr.

Session on Circuit-Breaker Rating

1. *Rating and Selection of Oil Circuit Breakers*, by E. M. Hewlett, J. M. Mahoney and G. A. Burnham.

2:30 P.M.

Session on Meters and Measurements

2. *A New Standard for Current and Potential*, by C. T. Allcutt.
3. *The Thermoelectric Standard Cell*, by C. A. Hoxie.
4. *The Character of the Thermal Storage Demand Meter*, by P. M. Lincoln.
5. *Measurement of Power Losses in Dielectrics of Three-Conductor High-Tension Cables*, by F. M. Farmer.

6:30 P.M.

Informal dinner at Cafe Boulevard subscription $2 dollars per cover.

President Rice will speak on some timely topic.

8:30 P.M.

Lecture, "Some Applications of the Electromagnetic Theory to Matter" by Dr. A. C. Crehore.

To be followed by discussion.

Saturday, February 16

10:30 A.M.

Session on Alternating-Current Commutator Motors

6. *Commutation in Alternating-Current Machinery,* by Marius A. C. Latour.
7. *The Secomor—A Kinematic Device which Imitates the Performance of a Series-Wound Polyphase Commutator Motor,* by V. Karapetoff.
8. *The Polyphase Shunt Motor,* by W. C. K. Altes.

Informal Dinner

For the convenience of members and guests in attendance at the Convention an informal dinner will be held at Cafe Boulevard, 41st Street and Broadway, on Friday evening, February 15, 1918, at 6:30 o'clock. This dinner will be served promptly in order that all present will be able to reach the Engineering Societies Building in time for the evening session.

The subscription price is $2.00 per person. Tickets are on sale at Institute headquarters.

No definite seating arrangements will be made but tables will be available accommodating eight persons. A table will be reserved for any group of eight upon request to the Dinner Committee at Institute headquarters prior to 5:00 p.m., Friday, February 15th.

Hotel Arrangements

As ample hotel accommodations are available in the immediate neighborhood of the Engineering Societies Building, no special arrangements have been made. Members will therefore make their own hotel reservations. As the New York hotels are unusually crowded this winter, members are advised to make reservations, well in advance.

Transportation

No special transportation rates are available and members should consult their local ticket agents regarding routes and rates. Parlor and sleeping car accommodations should be engaged in advance.

A. I. E. E. MEETING IN MARCH

The 338th meeting of the A. I. E. E. will be held in Cleveland, Ohio, March 8, 1918. This will be an inter-sectional meeting under the auspices of the Cleveland, Pittsburgh, Toledo, Toronto and Detroit Sections and there will be two technical sessions, one in the afternoon and one in the evening.

The evening session will be a joint session in participation with the Association of Iron and Steel Electrical Engineers, and each society will present a paper on the general subject of rolling-mill motors.

The following program of technical papers has been tentatively arranged:

Design of Underground Distribution for Electric Light and Power Systems, by G. J. Newton.

Selection of Steel Mill Auxiliary Motors and Control as Affected by Mechanical Features of the Drive, by J. D. Wright.

Some Considerations in Determining the Capacity of Rolling Mill Motors, by Robert F. Hamilton.

Another paper will be presented on behalf of the Association of Iron and Steel Electrical Engineers, the title of which will be announced later.

An informal dinner will be held between the technical sessions at 6:30 p. m.

Complete details of this meeting will be included in an announcement which will be issued about February 20th.

SPECIAL MEETING ON LIGHTING CURTAILMENT

There will be a special meeting of the Illuminating Engineering Society on Thursday evening, February 14th, in the auditorium of the Engineering Societies Building, 29 West 39th Street, New York City, at 8:15 p.m. for the purpose of discussing the question of lighting curtailment.

A paper will be presented by Mr. Preston S. Millar, General Manager of the Electrical Testing Laboratories and Chairman of the Committee on War Service of the Illuminating Engineering Society. The author will present figures dealing with the coal consumption question including the coal employed for lighting throughout the country and the amount which may be saved; methods of accomplishing the results expected through the curtailment of lighting; the present status of artificial lighting used for various purposes and other facts pertinent to this subject.

A number of prominent men in close touch with both the coal and lighting situations have been invited to speak personally or send a representative.

The question of the curtailment of lighting is a very important one at present and Mr. Millar will present facts and figures in this connection which will be a survey of the present situation throughout the country.

Members of the A. I. E. E. are cordially invited to attend this meeting.

FUTURE SECTION MEETINGS

Baltimore.—February 8, 1918. Subject: The Extension of Central Station Service with Special Reference to War Industries.

Boston.—February 5, 1918. Subject: Educational Symposium.

Chicago.—February 25, 1918. Subject: Electric Furnaces. Speakers: Messrs. Thaddeus Baily and John A. Seede.

Cleveland.—February 18, 1918. Speaker: L. P. Crecelius.

Los Angeles.—February 12, 1918. Subject: Power Costs, by C. A. Copeland.

Lynn.—February 13, 1918. Subject: What the World War will Do to Lynn.

Philadelphia.—February 7, 1918. Subject: Application of Oscillatory Currents to Heating and Electric Furnace Practise. Speakers: Dr. Edwin F. Northrup, Guilliam H. Clamer. Joint meeting with Franklin Institute.

February 11, 1918, Engineers Club. Subject: Students.

Pittsburgh.—February 12, 1918. Subject: Electrical Equipment for Gasoline Automobiles.

Pittsfield.—February 16, 1918. Subject: The Allied Message to America. Speaker: Augustus Post.

Portland.—February 8, 1918. Subject: Electric Smelting of Iron.

Spokane.—February 15, 1918. Subject: Symposium on Distribution.

St. Louis.—February 27, 1918. Subject: Electricity in Mines.

PUBLICATION OF TECHNICAL WORK OF THE JOINT COMMITTEE ON INDUCTIVE INTERFERENCE BY THE CALIFORNIA RAILROAD COMMISSION

The Joint Committee on Inductive Interference, organized in December, 1912, by the California Railroad Commission and authorized to conduct an investigation of the problem of inductive interference to communication circuits by parallel power circuits has completed its work, after continuously investigating this subject for over five years at a cost of over $100,000.

Some of the general conclusions have been published at different times during the progress of the investigation, but practically none of the technical data have thus far been made generally available. From time to time during the course of this work, technical reports have been prepared which give the data

obtained from the tests and the results and conclusions derived from both the tests and from theoretical studies Thirty of these technical reports have been selected as being of such general interest and applicability to warrant publication.

In addition to the technical reports the publication will contain final recommendations for rules for the prevention and mitigation of inductive interference and valuable historical matter concerning the investigation with general and technical discussions on the subject.

The book will have a complete index and contain approximately 1000 pages with over 400 drawings and 30 photographs.

The publication is contingent upon obtaining, in advance, a sufficient number of subscriptions to cover the actual cost of printing and binding at not to exceed, and probably considerably less than, $10.00 per set (1 or 2 volumes.)

If you are interested in this problem you will find these reports of considerable value, and you should enter your order at once. As the number of copies printed will be limited, only those subscribing in advance can be assured of receiving copies in the event the number of subscriptions justifies the publication. Those who place subscriptions will be advised as soon as possible whether the publication will be undertaken and the approximate cost per set. Do not send any money until you receive such notice. Address all communications to California Railroad Commission, Attention Richard Sachse, Chief Engineer, 833 Market Street, San Francisco, Cal.

GOVERNMENT SERVICE

The Aviation Section, Signal Reserve Corps has immediate need for the following three classes of men:

(a) Graduates of recognized technical schools with the degrees of civil engineer mechanical engineer, electrical engineer, etc., and subsequent practical experience with gas engines. Men of this class, if otherwise acceptable, may be commissioned direct in the Signal Reserve Corps, without being sent to the Ground School.

(b) Men who are not graduates of technical schools, but who have had shop experience, which gives them a practical knowledge of gas engines, equivalent to that required of the graduates. These may be commissioned after completing a course in one of the Ground Schools, established for the purpose.

(c) Administrative and executive experience in connection with shop work or in connection with the manufacture or maintenance of machinery, not necessarily gas engines, especially in a shop employing approximately thirty mechanics, is valuable and should qualify men for commissions, after completing a course in the Ground School.

(d) Application should be made to the President of the Aviation Examining Board, 104 Broad St., New York City, who will act on all applications immediately.

Ordnance Department.—The Ordnance Department of the Army urgently needs several thousand civilian workers. The actual fighting forces will be powerless without such an efficient civilian army behind them. The list of openings includes, clerical positions of many types, testing positions, mechanical trades positions, draftsmen and inspectors. Salaries very from $2.75 to $5.75 per day and from $480 to $3,000 per year. Many of the clerical positions are open to women as well as men. Positions paying higher salaries will be filled through promotion.

For further information apply to the representative of the United States Civil Service Commission at the post office or customhouse in any city or to the Civil Service Commission in Washington, D. C.

Organization of the 33rd Engineers.—There is now forming at Camp Devens,

Ayer, Mass., under the command of COLONEL MARK BROOKE, C. E., U. S. A., a regiment of engineers for general construction work in France. In it are offered to men with construction experience the greatest opportunities of any unit thus far organized. Construction superintendents and foremen, civil and mechanical engineers, surveyors, clerks, timekeepers, paymasters, stenographers and supply men, etc., are needed. Men showing ability and qualifications will have the chance to become non-commissioned officers, ranking as high as master engineer, senior grade, the highest in the service. As soon as the personnel of the regiment is completed and the equipment shipped it will be sent "over there," where men desiring to enter the big field which will be open after the war will have an unusual opportunity. It is hoped that a large number of college and technical graduates will volunteer.

Men of draft age may join by applying by mail to Headquarters 33rd Engineers, Camp Devens, Ayer, Mass. State age, address, occupation, draft status and number, name of local board and signify desire to volunteer for immediate service in this regiment.

Men not in the draft, between 31 and 41, may enlist at the nearest U. S. Army Recruiting Station, specifying that they are enlisting for service with the 33rd Engineers.

Bureau of Ordnance, Navy Department.—Competent draftsmen needed, men who are graduates in mechanical engineering from a technical school or college of recognized standing and have had some drafting room experience, or men who are competent designers of heavy machinery, engines or shop tools, and have had a number of years drafting room experience, are eligible for these positions. The pay ranges from $4.00 to $6.88 per diem, depending upon the qualifications of the draftsman. There are at present a number of vacancies in the rating of draftsman at the Washington Navy Yard. Additional information may be had by addressing the Commandant and Superintendent, Naval Gun Factory, Navy Yard, Washington, D. C.

Trench Warfare Section, Ordnance Department: The Trench Warfare Section of the Ordnance Dept. desires to get in touch with young men of technical training who can become candidates for commissions in the Ordnance Officers Reserve Corps, particularly young men over draft age, or in deferred draft classifications, who are physically sound, whose earning capacity is at least $1700 a year, who have good characters, some business experience, university training, and some technical skill—obtained either at school or afterwards through business experience and practical shop work.

If notified to come to Washington, it will be necessary for these men to interview Capt. Hudson Millar, 1800 Virginia Ave., Washington, D. C. They must bring three original letters of recommendation from American citizens, and should be prepared to stay in Washington at least three days. They are specifically advised that the trip will be made at their own expense, and that no assurance can be given them that their applications will be favorably considered.

Address all communications to E. J. W. RAGSDALE, Lt. Col. Ordnance, N. A., Trench Warfare Section, Engineers Bureau, 1800 Virginia Ave., Washington D. C.

A. I E. E. HONOR ROLL

Members of the American Institute of Electrical Engineers in Army and Navy service with the United States and her Allies.

This list supplements those published in the December and January PROCEEDINGS and includes only those members who are in the armed forces and who have responded to the War Service card sent to the membership on Sept. 15, 1917 or have otherwise communicated with Institute headquarters.

Members in Army and Navy service who have not been listed are requested to furnish the Institute with their proper military designation.

ALBRECHT, F. C.
Captain, Ordnance, R. C.
ALLEN, E. W.
Captain, 341st. Infantry, N. A.
ANDERSON, STEWART W.
First Lieutenant, 307th Engineers.
ATKISSON, EARL J.
Lieutenant Colonel, 30th Engineers, N. A.
BARRETT, SAMPSON K.
Lieutenant, junior grade, U. S. N. R.F.
BARTLETT, C. C.
116th Engineers.
BECHLEM, A. W.
Lieutenant, Camp Lee.
BODENMULLER, H. R.
Sergeant, 348th Infantry.
BROADBENT, W. W.
23rd Engineers.
BROWN, CHARLETON M.
Lieutenant, junior grade, U. S. N. R. F.
BROWN, GEORGE N.
First Lieutenant, Engineer, R. C.
BROUN, HUGH A.
Aviation Section, Signal Corps.
CALDWELL, BRICE J.
Lieutenant, junior grade, U. S. N. R. F.
CARLETON, F. V.
First Lieutenant, 62nd Infantry.
CARROLL, EMIL J.
Lieutenant, junior grade, U. S. N. R. F.
CLARK, R. PHILIP
First Lieutenant, Infantry, R. C.
COBB, FRANCIS C.
Lieutenant, junior grade, U. S. N. R. F.
COLLOPY, BERTRAM C.
Machinist Mate, U. S. N. R. F.
CORNELIUS, CLINTON C.
Aviation Section, Signal Reserve Corps.
COUPER, H. W.
Second Lieutenant, Ordnance, R. C.
CRAWFORD, WM. W.
First Lieutenant, Engineer, R. C.
CRICHTON, L. N.
Lieutenant, junior grade, U. S. N. R. F.
CRITCHFIELD, R. M.
Ensign, U. S. N. R. F.

KEY TO ABBREVIATIONS.

N. R. F.—Naval Reserve Force.

R. C.—Reserve Corps.

CROCKETT, ALBERT S.
Electrician, U. S. N. R. F.
CUSTER, WM. O.
Electrician, U. S. Navy.
DANIELSON, WILMOT A.
Captain, Coast Artillery Corps.
DANKO, JOSEPH P.
Radio Engineer, Signal Corps.
DARROW, RAYMOND C.
Lieutenant, junior grade, U. S. N. R. F.
DAVIS, ARCHIBALD H., JR.
Lieutenant, junior grade, U. S. N. R. F.
DAVISSON, HENRY L.
Captain, Stevedore Regiment, U. S. Army.
DAY, RICHARD F.
Aviation Section, Signal Corps.
DE WOLF, R. D.
Lieutenant, U. S. Navy.
DICHMAN, ERNEST W.
Aviation Section, Signal Corps.
DOBSON, GEO. G.
First Lieutenant, Signal R. C.
DOTY, PAUL
Major, Engineer, R. C.
EDEL, ALBERT F.
Lieutenant, junior grade, U. S. N. R. F.
EELLS, H. W.
Captain, Engineer, R. C.
ERICKSON, CARL JOSEPH
Aviation Section, Signal R. C.
EVANS, CLARENCE TURNER
Lieut. Commander, U. S. N. R. F.
EVANS, RICHARD W.
Second Lieutenant, R. C.
FAY, FRANK H.
Lieutenant, Signal R. C.
FECHT, A. J.
First Lieutenant, Engineer, R. C.
FITZGERALD, THOMAS
Major, Infantry, R. C.
FLEET, ARTHUR H.
Lieut. Commander, U. S. N. R. F.
FRANCY, C. W.
First Lieutenant, Engineer, R. C.
FULLER, FLOID M.
Lieutenant, U. S. N. R. F.
GAY, FRAZER W.
Lieutenant, junior grade, U. S. N. R. F.
GEBHARDT, CHAS. W.
Officers Training Camp.

GILES, GEORGE S.
U. S. N. R. F.
GILLETTE, GEORGE W.
Captain, Engineer, U. S. Army.
GIROUX, ROY M.
U. S. N. R. F.
GLASPEY, R. M.
Captain, Signal R. C.
GOMEZ, LOUIS G.
First Lieutenant, 323rd Field Signal Battalion, Camp Funston.
GRANT, FRANK L., JR.
First Lieutenant, Signal R. C.
GREEN, SAMUEL G.
First Lieutenant, Ordnance, R. C.
HALL, HARRY Y.
Captain, Engineer, R. C.
HANCOCK, EDWARD A.
Warrant Gunner, U. S. N. R. F.
HARALSON, NEWTON M.
Equipment Division, Signal Corps.
HART, A. D.
Lieutenant, junior grade, U. S. N. R. F.
HART, A. L.
Second Lieutenant, Signal Corps.
HAY, W. O.
Lieutenant, junior grade, U. S. N. R. F.
HAYS, LOWELL K.
305th Engineer Train, Camp Lee.
HENKE, EDMUND J.
Lieutenant, R. C.
HOOPER, WILLIAM E.
Lieutenant, junior grade, U. S. N. R. F.
HOPE, ROBERT D.
Captain, Ordnance, R. C.
HOWARD, DAVIS G.
Lieutenant, junior grade, U. S. N. R. F.
HOWARD, ROBERT B.
Signal Corps.
HUDSON, WILLIS F.
Ensign, U. S. N. R. F.
HUNTER, RICHARD B.
Lieutenant, junior grade, U. S. N. R. F.
HUTCHINSON, GEORGE E.
Lieutenant, U. S. N. R. F.
HYER, BENJAMIN B.
Major, Cavalry, U. S. Army.
IRVING, G. JR.
Captain, Coast Artillery, R. C.
JACKSON, DUGALD C.
Major, Engineer, R. C.
JENNEY, L. R.
Lieutenant Commander, U. S. N. R. F.
JENKINS, RAYMOND D.
National Army.
JENSEN, J. O.
First Lieutenant, 116th Engineers.
JOHNSON, L. D.
246th Aero Squadron.
JONES, PAUL S.
U. S. N. R. F.
JUNKINS, RAYMOND D.
National Army.
KELLY, RALPH
Lieutenant, junior grade, U. S. N. R. F.
KEYES, EDWIN F.
Lieutenant, junior grade, U. S. N. R. F.
KOUWENHOVEN, WILLIAM B.
Officers Training Camp.
KRATZ, A. B.
Major, Engineer, R. C.
LEWIS, ISAAC N.
Colonel, U. S. Army.
LINDSAY, H. D.
Lieutenant, junior grade, U. S. N. R. F.
LOEBENSTEIN, JULIAN.
Second Lieutenant, Engineer, R. C.
LOWELL, ROBERT T. S.
Lieutenant, U. S. Navy.
LUNSFORD, JESSE B.
Ensign, U. S. N. R. F.
LYFORD, OLIVER S.
Major, Ordnance, R. C.
LYTLE, JAMES H.
Lieutenant, junior grade, U. S. N. R. F.
MAC CUTCHEON, ALECK
Lieutenant, junior grade, U. S. N. R. F.
MAC LENNAN, TELFORD
New Zealand Division, British Expeditionary Force.
MARKLEY, F. R.
Lieutenant, Engineer, R. C.
MARTIN, RICHARD L.
346th Field Artillery, N. A.
McCULLOCH, G.
Captain, Instructional Staff.
Mc DOWELL, CLYDE S.
Lieutenant Commander, U. S. Navy.
McGUIRE, WILLIAM P.
Second Lieutenant, Engineer, R. C.
McLEARY, SAMUEL H.
Captain, Coast Artillery Corps.
METCALFE, V. E.
Lieutenant, junior grade, U. S. N. R. F.
MIKALOFF, JOHN P.
Electrician, U. S. N. R. F.
MILLIS, JOHN
Colonel, Engineer, U. S. Army.
MILLER, THOMAS LEE
Lieutenant, Signal Corps.
MILLS, HARRY A.
First Lieutenant, Signal R. C.
MOORE, EDMUND B.
First Lieutenant, Infantry, R. C.
MULLEN, FRANK B.
Lieutenant, junior grade, U. S. N. R. F.
MUNDO, CHARLES J.
First Lieutenant, Engineer, R. C.
MUNYAN, EARL A.
Ensign, U. S. N. R. F.
NEARY, E. J.
Lieutenant, junior grade, U. S. N. R. F.
NORRIS, ALBERT
Lieut. Commander, U. S. Navy.
NORSA, RENZO
Captain, 14th Army Corps, British Expeditionary Force.
PEASE, LEWIS A.
Lieutenant, junior grade, U. S. N. R. F.
PEASLEE, WILLIS D. A.
Captain, U. S. Army.

PENNELL, ALCOTT J.
Lieutenant, junior grade, U. S. N. R. F.
PERNOT, FREDERICK E.
Captain, Ordnance, R. C.
PERRY, F. GARDINER
Captain, Coast Artillery, R. C.
PETERSON, J. C.
Captain, U. S. Army.
PIKE, CLAYTON W.
Major, Ordnance, R. C.
RADLEY, GUY R.
Lieutenant, junior grade, U. S. N. R. F.
RANKIN, RALPH S.
Lieutenant, junior grade, U. S. N. R. F.
READ, ERNEST K.
Corporal, 103rd Field Battalion.
REDDIE, WM. W.
Lieutenant, junior grade, U. S. N. R. F.
REDING, JACOB J.
163rd Depot Brigade, Camp Dodge.
RICHMOND, WALDEMAR S.
Captain, Engineer, R. C.
RISTINE, C. S.
19th Engineers, U. S. Expeditionary Force.
ROE, CHARLES H.
Lieutenant, Engineer, R. C.
ROGERS, CLAYTON T.
Ordnance Dept.
ROOSEVELT, JOHN K.
First Lieutenant, Signal R. C.
SAGE, DARROW
Lieutenant, U. S. Navy.
SEGEL, HARRY
Lieutenant, junior grade, U. S. N. R. F.
SHORT, FRANK
First Lieutenant, U. S. Army.
SLOAN, R. D.
Lieutenant, junior grade, U. S. N. R. F.
SMITH, CARLETON W.
Lieutenant, junior grade, U. S. N. R. F.
SMITH, WALTER H.
Lieutenant, junior grade, U. S. N. R. F.
SORENSEN, ROYAL W.
Officers Training Camp.
SQUIER, GEO. O.
General, Signal Corps, U. S. Army.
STACK, ALVAN H.
Lieutenant, junior grade, U. S. N. R. F.
ST. CLAIR, BYRON W.
Chief Electrician, U. S. N. R. F.
STEINDORFF, KURT
Lieutenant, junior grade, U. S. N. R. F.
STIRLING, HARRY H.
Lieutenant, junior grade, U. S. N. R. F.
THOMPSON, ALEXANDER C.
Australian Flying Corps, Egypt.
THOMPSON, A. R.
Camp Lee, Va.
THOMSON, HARRY F.
Lieutenant, junior grade, U. S. N. R. F.
THROOP, GEORGE H.
Captain, U. S. Army.
TIMMERMAN, RAY
Lieutenant, junior grade, U. S. N. R. F.
TURNER, C. L.
Lieutenant, U. S. N. R. F.
UNDERHILL, CHARLES R.
Captain, Aviation Section, Signal R. C.
VEITCH, JAMES
Second Lieutenant, Royal Engineers.
VEITENHEIMER, FOSTER
Captain, Signal R. C.
VOLENTINE, PAUL
Lieutenant, junior grade, U. S. N. R. F.
WALDRON, LOUIS D.
Captain, Engineer, R. C.
WATTS, E. M.
Major, Canadian Infantry, British Expeditionary Force.
WELLS, GEORGE A.
Captain, Ordnance, R. C.
WHEELER, EARL
Captain, Engineer, R. C.
WHITING, H. R.
Officers Training Camp.
WILLIAMS, L. C.
Second Lieutenant, 116th Engineers.
WOOD, H. P.
Captain, Engineer, R. C.
WOOLFSON, MONROE G.
Lieutenant, junior grade, U. S. N. R. F.
YORKE, GEORGE M.
Major, Signal R. C.

Total including prevous lists 686.

THE 336th INSTITUTE MEETING IN BOSTON, NEW YORK AND CHICAGO

The 336th meeting of the Institute was an inter-sectional meeting held in Boston, January 8th, New York, January 11th and Chicago, January 14th, 1918. The paper entitled "*Effects of War Conditions on Cost and Quality of Electric Service,*" by Lynn S. Goodman and William B. Jackson was given under the auspices of the Committee on the Economics of Electric Service and presented at each of the three meetings by Mr. Jackson.

The Boston meeting with an attendance of eighty-five was presided over by Mr. Ira M. Cushing and the following men took part in the discussion: N. J. Neall, F. G. Sykes, J. W. Cowles, D. L. Galusha, J. F. Vaughan, H. S. Osborne, Prof. D. C. Jackson and Prof. C. A. Adams.

The New York meeting was called to order by President E. W. Rice, Jr., who made a few remarks relative to the many advantages of the "Split Meetings" innovation introduced at this session, through which the same paper would be delivered at several places. Secretary Hutchinson then abstracted three written discussions by F. A. Bryan, Mortimer Freund and R. G. Hudson. President Rice then formally opened the discussion in which the following men took part: B. J. Arnold, Philip Torchio, Philander Betts, W. S. Gorsuch, H. M. Hobart, D. C. Jackson, F. H. Bartlett, W. Sykes, W. N. Smith, J. J. Harold and W. B. Jackson.

At the Chicago session Mr. R. F Schuchardt presided and the following men engaged in the discussion: F. A. Coffin, F. H. Bernhard, A. Honegger, C. A. Keller, G. H. Lukes, J. K. Mabbs, C. W. Pendell, D. W. Roper, R. F. Schuchardt and T. Vladimiroff. The attendance was about 75.

The written discussions abstracted at the New York meeting were also presented in abstract at both the Boston and Chicago meetings.

A. I. E. E. DIRECTORS' MEETING JANUARY 11, 1918

The regular monthly meeting of the Board of Directors was held at Institute headquarters on Friday, January 11, 1918, at 3:30 p.m.

There were present: President, E. W. Rice, Jr., Schenectady, N. Y.; Vice-Presidents, B. A. Behrend, Boston, Mass.; L. T. Robinson, Schenectady, N. Y.; A. S. McAllister, New York; Managers, John B. Taylor, Schenectady, N. Y., C. E. Skinner, Wilfred Sykes and Charles Robbins, Pittsburgh, Pa., N. A. Carle, Newark, N. J., Walter A. Hall, West Lynn, Mass., William A. Del Mar, New York; Treasurer, George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $7,126.55 was ratified.

The Secretary announced the following committee appointments made by President Rice since the December meeting: Transmission and Distribution, H. B. Dwight; Power Stations, W. L. Bird; Traction and Transportation, W. G. Gordon; Standards, Henry D. James and Harold S. Osborne; Board of Examiners, Clayton H. Sharp to succeed William McClellan, resigned; Library Board of the United Engineering Society, B. A. Behrend to succeed Harold Pender, resigned; Edison Medal, Carl Hering as Chairman to fill vacancy.

The report of the Board of Examiners of meetings held on December 26, 1917, and January 7, 1918, was read and the actions taken at those meetings were approved.

Upon recommendation of the Board of Examiners the following action was taken upon pending applications: 65 students were ordered enrolled, 69 applicants were elected to the grade of Associate, 2 applicants were reinstated to the grade of Associate, 4 applicants were elected to the grade of Member, 1 applicant was elected to the grade of Fellow, 2 applicants were transferred to the grade of Fellow, 7 applicants were transferred to the grade of Member.

Upon the recommendation of the Sections Committee, authority was granted for the organization of a Section in Erie, Pa.

Upon the petition of Professor E. W. Henderson, of the School of Mining, Queen's University, Kingston, Ontario, and upon recommendation of the Chairman of the Sections Committee, the organization of a Student Branch at that University was authorized, to be known as the Queen's University Branch.

The Secretary presented a final report from Mr. Preston S. Millar, Secretary-Treasurer of the International Electrical Congress, which had been planned to be held in San Francisco in September, 1915, but which had been postponed on account of the war, in-

cluding a financial statement showing an unexpended balance due to the Institute of $321.99, and $72.50 due to subscribers whose present whereabouts are unknown, to be turned over to them when they can be found. The financial statement was accompanied by a check for the full amount, $394.49.

The Board voted its appreciation of the work of Secretary Millar and his associates on the committee.

Announcement was made of the expiration on the fourth Thursday in January, 1918, of the term of Mr. Gano Dunn as one of the Institute's three representatives upon the Board of Trustees of the United Engineering Society.

Mr. L. T. Robinson was appointed to succeed Mr. Dunn for the term of three years, ending on the Fourth Thursday of January, 1921.

The special committee which had been appointed by the Board of Directors at its October, 1917, meeting to make eighty-five nominations of graduate electrical engineers in compliance with a request received from the Navy Department, reported the completion of its work and requested that it be discharged. The committee was discharged with the thanks of the Board.

A considerable amount of other business was transacted, reference to which will be found in this and future issues of the PROCEEDINGS.

PAST SECTION MEETINGS

Boston.—November 13, 1917, Mass. Institute of Technology. Illustrated lecture by Mr. F. W. Peek, Jr., on "The Phenomena of Lightning." Joint meeting with M. I. T. Branch. Attendance 285.

December 18, 1917. Owing to the absence of Mr. Clark T. Henderson, the scheduled speaker, due to an important business engagement, the meeting was turned into a questionairre. Dr. A. E. Kennelly consented to answer the questions. Attendance 75.

Cleveland.—December 14, 1917, Hotel Statler, Electrical League Club Rooms. Papers: (1) "The Use of Searchlights in War" by R. B. Chillas; (2) "Some Aspects of Light, Shade and Color," by M. Luckiesh. Joint meeting with local section of Illuminating Engineering Society. Attendance 47.

Denver.—December 15, 1917, Denver Athletic Club. Addresses by Messrs. Sands and Kennedy on "The Conservation of Coal in Industrial and Domestic Uses." Attendance 35.

Detroit-Ann-Arbor.—December 14, 1917, Detroit Board of Commerce Building. Address by Mr. Alex Dow on "Capital for Public Utilities, Its Nature and Cost." Attendance 220.

Ithaca.—December 13, 1917, Franklin Hall. Address by Mr. F. D. Newbury on "Some Everyday Problems in the Operation of Generators and Synchronous Converters." Attendance 46.

Los Angeles.—December 11, 1917, Public Library. Illustrated address by Mr. H. H. Cox on "Four Years Operation of the Big Creek Plant." Attendance 60.

Lynn.—December 19, 1917, Classical High School Hall. Mr. Simeon Lake gave an illustrated lecture on "The Submarine." Attendance 832.

January 2, 1918, G. E. Hall. Lieut. F. O. Crosby, of the British Royal Flying Corps, spoke on his experiences in the air and on the relation of Great Britain and the United States to the war. Cadet Officer Louis R. Corson, of the American vessel *Actaeon*, told of the formation of a convoy and of his experiences with enemy submarines and his escape after the *Actaeon* was torpedoed. Attendance 400.

Milwaukee.—December 12, 1917, Allis-Chalmers Club House. Mr. H. Freeman gave an address on "Forgings," and Mr. R. S. MacPherson spoke on "The Structure and Heat Treatment of Steel and Steel Forgings." After the lectures a visit was made to the Allis-Chalmers forging plant.

Panama.—December 16, 1917. Cristobal, C. Z. General discussion on Power Plant Practise.

Philadelphia.—December 10, 1917, Engineers' Club. Papers: (1) "Annual Relief Map and Load Factor Analysis" by Wm. Le Roy Robertson; (2) "Underground Conduit Construction," by H. C. Blackwell. Mr. Blackwell's paper was illustrated by lantern slides and moving pictures. Attendance 152.

Pittsfield.—December 20, 1917, Hotel Wendell. Lecture by Police Inspector Stacy R. Burckes, of Lynn, on "The Bertillon Finger Print Science." Moving pictures showing naval manouvers and pictures taken at Battle of the Somme.

January 3, 1918, Hotel Wendell. Address by Mr. D. M. Buck on "The Manufacture of Steel," illustrated by moving pictures. Attendance 105.

Rochester.—December 28, 1917, Rooms of Rochester Engineering Society. Address by Mr. K. O. Wolcott on "Automobile Lighting and Storage Systems."

St. Louis.—December 20, 1917, Mercantile Club. Annual dinner of the Section. Reports of committees for the year were submitted. Election of officers as follows: chairman, H. W. Eales; secretary-treasurer, B. F. Thomas. Following the business meeting Mr. R. J. Russell spoke on "The Relations of the Manufacturers and Engineers to the Government." Attendance 25.

Schenectady.—December 21, 1917, Edison Club Hall. Mr. S. T. Dodd gave an address on "High Speed Electric Locomotives." Attendance 123.

January 4, 1918, Edison Club Hall. Address by Mr. C. A. Winder on "Niagara Power or a Real Coal Shortage." Attendance 114.

Seattle.—November 27, 1917, Arctic Building. Lecture by Mr. A. E. Green on "The Electric Furnace." Election of officers as follows: chairman, John Harisberger; secretary, G. Dunbar.

Spokane.—December 21, 1917, Chamber of Commerce. Paper: "Corona as Affecting Transmission Lines," by Charles M. Fisher. Discussion by Prof. H. V. Carpenter on "The Application of the Electron Theory." Attendance 26.

Toronto.—December 21, 1917, Engineers' Club. Address by Major Charles H. Riches on "History and Development of Patents." Attendance 30.

Washington.—December 11, 1917, Cosmos Club Hall. Paper: "Electric Furnaces and Welding," by J. A. Seede. Paper was illustrated by lantern slides. Mr. R. H. Dalgleish spoke on "Electric Welding on the Car Line of the Capitol Traction Company." Attendance 106.

PAST BRANCH MEETINGS

University of Arkansas.—December 10, 1917, Engineering Hall. Papers: (1) "Industrial Electrical Trucks," by Bohart Cowan; (2) "Iron Wire Transmission," by A. O. Evans; (3) "Sparks," by E. L. Hollabaugh. Attendance 9.

Polytechnic Institute of Brooklyn.—December 15, 1917, Auditorium. Moving pictures of Schenectady works of General Electric Company, and photoplay of the life of Edison. Attendance 80.

December 18, 1917, Mailloux Library. Election of officers as follows: chairman, G. Hotchkiss; 2nd vice-chairman, T. C. Schwab; secretary, E. A. Demonet; treasurer, T. M. Feder. Attendance 24.

Bucknell University.—Election of officers as follows: president, C. W. Mason vice-president, W. E. Trimble; secretary-treasurer, Leon H. Noll.

Colorado State Agricultural College.—December 11, 1917, Electrical Building. Paper: "Electrical Heating and Cooking," by R. A. Brickson. Demonstration of voltage regulator by Mr. L S. Foltz. Attendance 10.

University of Colorado.—December 20, 1917, Engineering Building. Address by Mr. E. A. West on "Coal Conservation and Power Generation." Mr. Webber also spoke on the above subject. Attendance 25.

University of Idaho.—Election of officers as follows: chairman, V. E. Pearson; secretary-treasurer, L. J. Corbett; member of executive committee, D. Nankervis.

University of Kentucky.—December 10, 1917. Papers: (1) "Insulators," by B. B. Russell; (2) "Load Curves," by C. Nicholoff. Election of officers as follows: president, J. M. Hedges, Jr., secretary, Robert M. Davis; treasurer, W. S. McDougle.

Lafayette College.—January 12, 1918. Pardee Hall. Paper: "The Cost of the Kilowatt-Hour," by Mr. Hagey. Attendance 15.

Lehigh University.—January 3, 1918. Papers: (1) "Some Problems in Transportation," by E. C. Spring; (2) "Cottrell Process for Precipitation of Smoke," by H. M. Fry. Attendance 48.

Massachusetts Institute of Technology.—December 18, 1917, Smith Hall. Illustrated address by Prof. Charles M. Allen on "Gasoline." Attendance 78.

University of Michigan.—December 7, 1917. Illustrated address by Mr. E. E. Kearns on "Induction Motors." Motion picture entitled "King of the Rails." Attendance 39.

January 11, 1918. Address by Mr. M. Luckiesh on "The Lighting Art—Its Practise and Possibilities." Joint meeting with Detroit-Ann-Arbor Section. Attendance 80.

University of Missouri.—December 17, 1917, Y. M. C. A. Building. Paper: "Design Features and Application Possibilities of the Homo-Polar Dynamo," by G. A. Irion. Attendance 26.

Ohio Northern University.—January 9, 1918. Address by Prof. L. C. Sleesman on "Poisons and Poisonous Gases." Attendance 29.

Purdue University.—November 13, 1917, Electrical Building. Addresses as follows: (1) "Fundamental Principles of Watthour Meters;" (2) "Watthour Meters," by Mr. Pyle. Attendance 45.

November 27, 1917, Electrical Building. Addresses as follows: (1) "General Repair Work and Methods Used in Repairing Electric Motors and Generators," by R. W. Burns; (2) "Late Standardized Army Truck of the Three-Ton Class," by G. L. Ohmart. Attendance 41.

December 11, 1917, Electrical Building. Inspection trip conducted by Professors Ewing and Emrick. Attendance 42.

Rensselaer Polytechnic Institute.—December 18, 1917, Sage Laboratory. Address by Mr. Walter D'Arcy Ryan who gave a "Pictorial Review of the History of Lighting, including the Illumination of the Panama-Pacific International Exposition." Attendance 200.

Stanford University.—Election of officers as follows: chairman, Fred G. Hampton; secretary, Berndt Widell; treasurer, Frank R. Miller. Address by Prof. Harris J. Ryan on "The Relation of the Institute to Its Student Branches. Attendance 15.

Syracuse University.—December 13, 1917. Paper: "The Use of the Orsat," by W. J. Yordon.

December 20, 1917. Subject: The Salmon River Hydroelectric Plant. Attendance 10.

Agricultural and Mechanical College of Texas.—January 9, 1918, Auditorium. Motion pictures "The Workings of the Panama Canal," by courtesy of the General Electric Company. Attendance 215.

Washington State College.—December 14, 1917. Paper: "The Design and Construction of Modern Concrete Dams," by M. K. Snider. Attendance 25.

January 11, 1918. Address by Mr. J. B. Fisken on "The Engineer; His Opportunities and His Duties." Attendance 47.

HYDROELECTRIC DEVELOPMENT

The following statement entitled "Hydroelectric Development" was, on the special invitation of the Water Power Committee of the U. S. Chamber of Commerce, prepared by the Executive Committee of the Engineering Council for presentation by its representative, Mr. Calvert Townley, Fellow of the A. I. E. E. and member of the Council, before a committee of the U. S. Chamber of Commerce in Washington on January 14, 1918.

"It is my pleasant duty to appear before you by vote of the Executive Committee of Engineering Council, in response to your kind invitation of January 10th. Being empowered as it is to speak for the American Society of Civil Engineers; the American Institute of Mining Engineers: the American Society of Mechanical Engineers and the American Institute of Electrical Engineers on matters of common concern to all of these bodies, the Engineering Council's official utterances concern only such underlying principles and economic facts as are endorsed by all engineers and beyond the field of controversy. These Societies are scientific and professional. They, therefore, refrain from expressing views on legal, political and commercial questions except when such are closely linked with essential engineering facts. The statements which I am privileged to make to you are not expressions of my personal views nor of those of any group. They have been submitted to, and approved by, the Executive Committee of Engineering Council which believes them to fall within the definition given.

"The introduction of electricity as a means for transmitting power over considerable distances and its subsequent rapid development completely changed the status of hydraulic power. Previously such power could only be used near falling water. Now it is commercially available in convenient form within a radius, in some instances, up to 200 miles, a fact that has made it possible to utilize water powers even when located in remote and inaccessible places. Indeed to-day practically all hydraulic power developments of any magnitude are hydroelectric. Along with improvements in the art of electrical transmission have come equally rapid developments in the application of electricity. Electric light has become almost the universal illuminant. Electric motors largely drive our factories and propel all our street cars. They have made substantial progress in replacing steam locomotives on some large railroads, while the manufacture of nitrogenous products for explosives and fertilizers, and of such products as abrasives and aluminum, depends for its commercial success on electrochemistry. In an endeavor to supply the demand for electric current thus created large central generating stations have been established in or near all large centers of population.

"In the light of the foregoing, it might seem reasonable to suppose that a large proportion of the modern demand for electric current would be supplied from the energy in falling water. Such, however, is not the case. Accurate statistics are difficult to obtain but some approximate totals may prove illuminating. It has been estimated by a careful engineer that in 1911 there were over 26,000,000 steam engine horse power capacity in use, (including railroad locomotives) in the United States. The aggregate water horse power developed and undeveloped has been computed as around 60,000,000. Of this latter the U. S. Census of 1912 gives 4,870,000 as developed and in a report of January, 1916, the Secretary of Agriculture estimates this total to have been increased to 6,500,000. Making liberal allowances for correction in these several figures it seems probable that there are in service from four to five times as many steam as water horse power and that there are still undeveloped water horse power equal to at least twice that of all the steam capacity in service. Some of the undeveloped

power sites are too remote from any market to be now utilized, and an uncertain number are not commercial prospects; but even so it is clear that the possibilities of additional development are very great.

"There are two fundamental causes which have militated against the substitution of hydroelectric for steam-electric power. One is economic and permanent; the other is statutory and therefore subject to modification. Both reasons apply to some powers but neither, fortunately, to all. The economic and permanent reason is high cost of development due to natural conditions. Electric power generated by falling water is inferior to that generated by steam in every particular except cost and therefore, water driven service must be cheaper than steam driven in order to justify its existence. The price for service depends primarily on cost and cost divides itself naturally into two main items, namely, operation (including maintenance) and fixed charges. As an hydroelectric plant consumes no fuel its operating cost is less than that of an equivalent steam-driven plant. On the other hand a steam plant costs usually only from one-fifth to one-half as much per unit of capacity as an hydroelectric plant so that the latter must carry very much heavier fixed charges. This disability of water service is usually even greater than the ratio of the costs of two equivalent complete developments. A power enterprise seldom comes into being with a market for its entire ultimate output. Therefore, when steam is to be the motive power, only such capacity is installed as initial demands require and the cost per unit is fairly proportional to that of the ultimate development. In a water development on the contrary, a large part of the cost is for riparian rights, for the dam, impounding reservoir, flume, forebay, etc., and for the transmission right-of-way, towers, etc., which must be at the start, largely provided and constructed for the complete installation. The obvious result is a greater fixed charge per unit of capacity and a higher cost per horse power delivered for sale. In forecasting the commercial prospects of a power enterprise the possible market must be studied and of course, a sale price for power decided upon. As this price is controlled by the cost of similar service from other sources, usually from steam, and as it must be attractive from the start, the additional burden of fixed charges on the initial part of an hydroelectric installation frequently forces the sale of its power below cost. The projectors of the enterprise then must rely for success on a sufficient subsequent increase in their markets. The possibility of an incorrect forecast of the extent of such increase and of the time when it may come imposes a serious business hazard against water and in favor of steam.

"It has been frequently pointed out that as the nation's coal supply is depleted, the cost of coal must rise, thus increasing the cost of steam-electric power as a competitor and raising the market value of hydroelectric power accordingly. The rising price of coal is a matter of record, but it is not so generally known that the improved efficiency of steam-producing machinery (boilers, engines, generators and auxiliaries) has more than kept pace, so that the net cost of producing electric power from coal has steadily declined. As applied to the pre-war period it may be stated that over a period of ten years the cost of coal has risen on an average one per cent per year while the cost of electric power produced from coal has fallen on an average two and one-half per cent per year. In addition to these facts—still referring to pre-war conditions—the cost of steam-electric generating equipment has been greatly reduced. This fact is due partly to the introduction and subsequent improvement of the steam turbine, and in part to the great increase in the size of the units now available. There is nothing to indicate that the limit of improvement in the design of steam prime movers has

been reached or is even in sight. It is, therefore, a reasonable assumption that further advances in the art will continue to occur and to cut down both the fixed charges and the operating cost of steam power as a competitor of water. The largest modern steam turbine has now some twelve times the capacity which the largest reciprocating engine had fifteen years ago. Stated another way, the cost of a steam-electric plant per unit of capacity just before the war was about one-third what it was fifteen years previous, while the energy it produces per pound of coal has increased fifty per cent. In addition to the development of steam prime movers the Diesel or the internal combustion engine is now coming largely into use as a further competitor of water power where fuel oil is available as in the southwestern district of the United States. The efficiency of these engines is considerably higher than that of the small size steam turbine and reciprocating engine. There has not been a like improvement in the efficiency nor a comparable reduction in cost of the small reciprocating steam unit and a natural result has been expansion of the central stations. As bearing on the water power situation, obviously many sites which fifteen years ago might have been developed to sell energy in successful competition with steam at its then cost could not now be so developed, and in consequence their development is no longer commercially possible. The cost of producing power from either water or steam is a function of load. Fixed charges remain practically unchanged in both instances where the output in energy be large or small but with a steam plant, increased output means increased fuel consumption while a water plant operates either with or without load with but little variation in expense. To illustrate by a concrete example representing not unusual conditions, suppose we assume a steam plant using two and a half pounds of coal per kilowatt-hour at a price of $3.00 per short ton and having a plant or output factor of 35 per cent—that is to say an output equal to 35 per cent of its theoretical output if every unit were loaded to capacity 24 hours each day of the year. Under these assumptions the cost of fuel per unit of installed capacity per year would be $11.50 and if the other operating and maintenance charge be assumed to fairly offset those of a water installation of equivalent size, $11.50 represents the additional fixed charges which the hydroelectric plant could carry and produce power at an equal cost. If the fixed charges, (interest, taxes, insurance and amortization) total 11.5 per cent, therefore, the hydroelectric investment per kilowatt capacity could exceed that of steam by $100. This is not an abnormal excess. Many hydroelectric developments exceed the cost of equivalent steam-driven systems by much greater amounts in which cases they become commercial prospects only if either coal be more expensive per unit of output, or the plant factor be higher, or some other operating or maintenance condition be more favorable. Further, as has been previously stated, hydroelectric power is inferior to steam-electric power. The reasons are elementary. Stream flow is subject to seasonal variation, and therefore to complete or partial interruption by drought in summer and by ice in winter. Floods are a menace. Long transmission lines may break from wind or sleet or the service be disarranged by lightning. The losses on such lines vary with load and are frequently responsible for annoying pressure variations. On account of these and other reasons hydroelectric power cannot prevail against steam competition at the same or a slightly lower price. It must be materially lower.

"We do not mean to imply that water power may not be a commercially practicable competitor of steam. Many successful hydroelectric installations give substantial proof to the contrary. We do wish most emphatically to combat however, the widely held but mistaken view that any water-driven plant

will produce power at lower cost than steam can and that the margin is so large investors generally are eagerly seeking a chance to put money into hydroelectric projects. The most careful investigation, frequently demanding substantial expenditure and the keenest scrutiny by experts, is needed to discriminate between worthy and commercially impractical projects, and the difference is often so small that the imposition of even what seem to be minor burdens is sufficient to turn the scale in favor of steam and entirely prevent what might otherwise be a desirable hydroelectric development.

"The second condition which vitally affects development is statutory. After ten years or more of discussion it has come to be generally agreed that our Federal laws discourage the development of a large proportion of the nation's water powers and remedial legislation has been considered at every session of Congress for many years. The legal obstacles are quite distinct and separate from the economic facts which have been previously described and are in addition thereto.

"Of the estimated 55,000,000 undeveloped water horse power in the entire country, approximately 40,000,000 is located within the boundaries of the thirteen so-called western water power states. In these same states the Federal Government still retains as proprietor 760,000,000 acres, or over two-thirds of the aggregate acreage of all these states taken together. In order to develop power in that section it is therefore nearly always necessary to use some part of this public domain if not for the dam site itself, at least for flowage, for transmission right-of-way or for some other purpose. Existing law forbids such use except under permit issued by the Secretary of the Interior and revocable without cause, at any time, by himself or his successor in office. It was once believed that revocation would only follow gross abuse well established by evidence, but the drastic action of a one-time Secretary of the Interior some years since to the contrary, disabused investors of this confidence and demonstrated by a sad object lesson the insecure tenure afforded by existing law. As funds for hydroelectric development must come from private sources, the unstable tenure imposed by this condition has constituted so great a hazard of loss that the private investor has been loath to assume it. The unfortunate—almost disastrous—result has been practical stagnation in water power development for many years. Many available power sites not in the western States, or not on the public domain are on navigable streams. For each such project a special Act of Congress is necessary. The difficulty of obtaining suitable rights by this means has been found so very great as largely to discourage, even if not entirely to prevent the developments affected. The several remedial laws recently considered by Congress recognize the essential facts and agree that the remedy is a new law containing the following provisions, namely. An indeterminate permit irrevocable during fifty years except for cause judicially determined, and continuing thereafter unless and until the Federal Government either renews its permit on mutually agreeable terms, or for itself or through a new permittee takes over at its fair value, the hydraulic works and certain other parts of the development. The various proposed laws differ as to what parts of the development may be taken; as to whether or not rentals shall be paid and their basis, and in many other particulars. Engineering Council does not consider itself expert in legal matters and will not undertake to discuss the relative merits of the different plans. It should be pointed out, however, that an hydroelectric enterprise being once successfully established, it is alike to the interest of the owners, of the Government and of the public that it should continue indefinitely without interruption. There is no economic rea-

son to be served by a cessation and the only reasons for providing a legal means of recapturing the installation and the water rights are, first, to preserve an additional measure of Government control against possible abuse by the permittee, and, second, against a remote contingency which might make it desirable that the Government would want to use the power for some other purpose. A successful power enterprise at the end of 50 years will have multiplied the capacity of its initial installation many times, variously estimated at from five to twenty. In doing so, it is almost certain that not only will the entire power available at the original site be fully developed but other powers as well, which latter may or may not be dependent upon Government permits. Still further, in nearly all cases steam plants as well as water plants are necessary. These steam plants are necessary to supplement hydroelectric power at periods of low water and in case of interruption, as well as, in some instances to provide increased capacity. In fact, modern practise is rapidly approaching that of providing steam capacity equal to 100 per cent of hydroelectric for the purposes stated. In any event, the growth of the enterprise over a term of years will be continuous and progressive. There will never come a time when it may be said to have been completed and subject to no further expansion. This continuing growth makes burdensome and usually abortive any attempt to amortize the investment, while the investment in other water powers or in steam plants or both, interconnected with, and generally dependent for their economic operation on the original development, renders the right to recapture that development only very onerous and one which constitutes a serious impediment to the free and full development of an enterprise which is otherwise most desirable from all standpoints. With respect to power sites on the public domain and on navigable streams the Government is in the position of seeking to have its resources developed without assuming any business hazard and without contributing either capital or credit. It would be unfortunate, in the light of past experience, if any new laws which may be enacted should put the Government in the position of bargaining with capital and of offering just sufficient incentive not to induce capital to undertake the developments desired, thereby, while apparently providing a remedy, in reality insuring a continuance of the present undesirable condition. Hydroelectric enterprises must compete with the demands of other industries for capital. Experience has shown that even without the imposition of additional financial burdens many of them are not sufficiently attractive to secure development and as the attractive prospects grade by imperceptible degrees into the unattractive ones, it is perhaps self-evident that every additional burden, however small, tranfers a percentage of such projects from commercial into uncommercial prospects. It is our belief that the benefits afforded the communities served by cheap power, and to the nation by the conservation of coal resulting from the substitution of a self-renewing for a non-renewable natural resource are far more valuable than is the exact solution of the question of restricting the returns to capital to their irreducible minimum. The present emergency due to the progress of the war has forcibly illustrated the importance of having developed the greatest possible number of water powers as a source of industrial power supply. As it consumes no fuel, the substitution of water for steam power would release to other uses all the extensive railroad and water facilities now engaged in transporting coal. It would similarly release a corresponding volume of labor now occupied in mining this coal and in operating such transportation agencies as well and the boiler room forces of the steam-power plants themselves."

ASSOCIATES ELECTED JANUARY 11, 1918

ALLEN, JAMES, Special Meter Tester, Counties Gas & Electric Co.; res., 554 Astor St., Norristown, Pa.

ARNOLD, BENJAMIN HOWARD, Supervisor of Employment, General Electric Co., Erie, Pa.

*BAGLEY, GLEN DAVID, Research Engineer, Mellon Institute of Industrial Research; res., 3420 Parkview Ave., Pittsburgh, Pa.

*BIRD, CHARLES WESLEY, Engineering Dept., Detroit Edison Co., Detroit; res., 213 Massachusetts Ave., Highland Park, Mich.

BOVEE, BENEDICT ARTHUR, Instructor, School of Engineering of Milwaukee; res., 917 4th Ave., Milwaukee, Wis.

*BUSCH, RALPH EMERSON, Testing Dept., General Electric Co.; res., 310 Lighthouse St., Erie, Pa.

CARR, H. D., Electrical Designer, Braden Copper Co., Rancagua, Chile, South America.

CANNADY, NATHANIEL ELLIS, State Electrical Engineer & Inspector, North Carolina Insurance Dept., Raleigh, N. C.

*CARTER, EARL L., Expert Telephone Engineer, Public Service Comm. of Indiana; res., 332 E. Walnut St., Indianapolis, Ind.

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CHAN, PING KEY, Electrical Draftsman, Electric Products Co., 1067 152nd St., Cleveland, Ohio; res., Canton, China.

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CURTIS, LEO HENRY, Electrical Tester, General Electric Co., Erie, Pa.; res., 703 Leon St., Dunkirk, N. Y.

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FOGERTY, JOSEPH SAMUEL, Tester, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 747 Franklin Ave., Wilkinsburg, Pa.

FROST, CLAY ABEL, Asst. Chief Electrician, Central Furnaces, A. S. & W. Co., Broadway & Erie R. R.; res., 3642 E. 120th St., Cleveland, Ohio.

GIBBS, RAYMOND T., Electrical Instructor, Franklin Union, 41 Berkeley St., Boston; res., Brookline, Mass.

*GOODWIN, WALTER COOK, Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 6032 Marie St., Pittsburgh, Pa.

GUYNES, W. M., Railway Motor Engg. Dept., General Electric Co., Erie; res., 2309 Wagner Ave., Wesleyville, Pa.

HANCOCK, EDWARD ARTHUR, Industrial Control Specialist, General Electric Co., Boston; res., 25 Washburn Ave., Auburndale, Mass.

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HARRIS, HARVEY LESTER, Sales Engineer, Stromberg-Carlson Tel. Mfg. Co.; res., 1077 Harvard St., Rochester, N. Y.

HART, JOY MANLEY, Cadet Engineer, Counties Gas & Electric Co.; res., 622 Swede St., Norristown, Pa.

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*HESS, A. FREEMAN, Div. Plant Engg. Dept., American Tel. & Tel. Co.; res., 2040 5th Ave., New York, N. Y.

*HILL, SCOTT S., Equipment Foreman, General Electric Co.; res., 1121 W. 8th St., Erie, Pa.

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ISDALE, JOHN S., Electrical Engineer, Imperial Munitions Board (Shipbuilding Section); res., 26 Nepean St., Ottawa, Ont.

KAISER, ALEXANDER A., Engg. Asst. to Revision Transformer Engr., Bell Tel. Co. of Pa.; res., 727 Morris St., Philadelphia, Pa.

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KLEIN, HARRY, Asst. Engr., Economics Div., Interborough Rapid Transit Co., 621 Broadway; res., 360 Beekman Ave., New York, N. Y.

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MARKLEY, RALPH E., Chief Motor Inspector, Counties Gas & Electric Co., Norristown; res., 2319 W. Cumberland St., Philadelphia, Pa.

MASSEY, MARK FULLER, Draftsman, Ordnance Office, War Dept.; res., 918, 23rd St. N. W., Washington, D. C.

MCCLENATHAN, ROY FRANK, Test Foreman, General Electric Co.; res., 204 E. 10th St., Erie, Pa.

METZNER, MAXWELL WALLACE, Testman, General Electric Co.; res., 13 W. 7th St., Erie, Pa.

*NAKAMURA, Y., Yoshiki-mura, Yoshiki-gun, Yamaguchi-ken, Japan.

NEWELL, LEWIS B., Efficiency Engineer, General Electric Co.; res., 61 Taylor St., Pittsfield, Mass.

*OEHLER, ALFRED G., Associate Editor, *Railway Electrical Engineer*, 2201 Woolworth Bldg., New York, N. Y.; res., Westfield, N. J.

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PFAFF, ROBERT WILLIAM, Electric Meter Foreman, Counties Gas & Electric Co.; res., 1005 W. Lafayette St., Norristown, Pa.

*POLSON, ALEXANDER VIVIAN, Sales Dept., Goulds Manufacturing Co.; res., 175 Fall St., Seneca Falls, N. Y.

RASMUSSEN, WM. CHRISTIAN OTTO, Assembling Dept., Safety Car Heating & Lighting Co.; res., 843 Communipaw Ave., Jersey City, N. J.

REINKE, EUGENE A., Sales Engineer, Stromberg-Carlson Telephone Mfg. Co.; res., 44 Faraday St., Rochester, N. Y.

RIDDLE, ROBERT BARKER, Asst. Elec. Engr., E. I. du Pont de Nemours & Co., Carney's Point, N. J.

ROE, RALPH COATS, Manager, Fairbury Office, Central Illinois Utilities Co., Fairbury, Ill.

SHANNON, WILLIAM J., Power Equipment Sales, New England Engineering Company, Waterbury; res., Warren Way, Watertown, Conn.

SMITH, ALBERT PARKER, General Foreman of Distribution, Counties Gas & Electric Co.; res., 507 Barbadoes St., Norristown, Pa.

*STAFFORD, JOHN WILLIAM, Signal Corps, U. S. National Army; res., 628 S. 4th St., Lafayette, Ind.

STEFFELAAR, JOANNES MARIE, Engineer, Patent Office of Holland, Hollanderstraat 86, The Hague, Holland.

STEINKE, JOHN JACOB, Testing Dept., General Electric Co.; res., 620 East 6th St., Erie, Pa.

STEVENS, GEORGE A. W., Foreman of Elec. Const., Stone & Webster Engg. Corp., Riverside Plant, Buffalo, N. Y.

*STEWART, RALPH BERRY, Instructor in Elec. Engg., Sibley College, Cornell Univ.; res., 715 E. Buffalo St., Ithaca, N. Y.

STRAWN, CHARLES MEREDITH, Chief Engineer, Counties Gas & Electric Co.; res., Airy & Hamilton Sts., Norristown, Pa.

THOMPSON, LEWIS M., Asst. Electrical Engr., E. I. du Pont de Nemours Powder Co., Wilmington, Del.; res., 5937 Summer St., Philadelphia, Pa.

TROWBRIDGE, DAVID FARRIS, Engineer in Engineering Dept., Cutler-Hammer Mfg. Co.; res., 148 14th St., Milwaukee, Wis.

WATTERSON, H. E., Chief Electrician, E. I. du Pont de Nemours & Co.; res., 10 Burnside St., City Point, Va.

WEIR, CHARLES, Chief Engineer, Power Station, Okere Falls, Rotorua, New Zealand.

WILLMARTH, GEORGE MARTIN, Instructor in Applied Electricity & Elec. Lab., Wentworth Institute, Boston; res., Brookline, Mass.

WINTE, HERMAN F., Chief Clerk, Lines, Costs & Records Dept., Detroit Edison Co.; res., 136 Vicksburg, Detroit, Mich.

*WOODWARD, ARTHUR COY, Engg. Dept., Chesapeake & Potomac Telephone Co., Baltimore; res., Arlington, Md.

*Former enrolled students.

Total 64.

MEMBERS ELECTED, JANUARY 11, 1918

ARNOLD, JAMES LORING, Prof. of Elec. Engg., N. Y. University, New York; res., 468 Warburton Ave., Yonkers, N. Y.

BURCH, WALTER S., Engineering Dept., Rochester Railway & Light Co.; res., 81 South Fitzugh St., Rochester, N. Y.

GAUDY, R. JARVIS, Chief Engineer, General Devices & Fittings Co., 817 W. Washington Blvd., Chicago; res., Evanston, Ill.

KAPPEYNE, JACOBUS, Engineer, Public Utilities Commission of the District of Columbia, Room 341 District Bldg., Washington, D. C.

FELLOW ELECTED, JANUARY 11, 1918

SCHROEDER, GIULIO, Chief Electrical Designer, British Westinghouse Electric & Mfg. Co., Ltd., Trafford Park, Manchester, England.

ASSOCIATES REELECTED, JANUARY 11, 1918

COCHRAN, CLYDE E., Chief Engineer, Elwell-Parker Electric Co.; res., 10925 Churchill Ave., Cleveland, Ohio.

HILDEBRANDT, HENRY A., Supt. of Buildings and Grounds, Univ. of Minnesota; res., 323 Church St. S. E., Minneapolis, Minn.

TRANSFERRED TO GRADE OF MEMBER, JANUARY 11, 1918

ALLING, SYDNEY, Engineer, Electric Distribution, Rochester Railway & Light Co., Rochester, N. Y.

BEAVER, JACOB L., Distribution Dept., Philadelphia Electric Co., Philadelphia, Pa.

CADBY, JOHN N., Consulting Engineer, Madison, Wis

CHASE, PHILIP H., Assistant Engineer, Public Service Electric Co., Newark, N. J.

HAZELTINE, LOUIS A., Acting Professor of Electrical Engineering, Stevens Institute of Technology, Hoboken, N. J.

TASSIE, ROBERT WILSON, Electrical Engineer, Havana Electric Railway, Light & Power Co., Havana, Cuba.

THOMPSON, JOHN WEST, District Manager, Central Mexico Light & Power Co., San Luis Potosi, Mexico.

TRANSFERRED TO GRADE OF FELLOW, JANUARY 11, 1918

McBERTY, FRANK ROBERT, Electrical Engineer, 34 Norfolk St., Strand, W. C. 2, London, England.

McNICOL, DONALD, Assistant Electrical Engineer, Postal Telegraph Cable Co., New York, N. Y.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings mentioned below, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

Recommended for transfer by the Board of Examiners December 26, 1917.

To Grade of Member

ARMSTRONG, EDWARD R., Experimental Engineer, E. I. Du Pont de Nemours & Co., Wilmington, Del.

MANSON, RAY H., Chief Engineer, Stromberg-Carlson Telephone Mfg. Co., Rochester, N. Y.

MERRILL, FRANK W., President, Merrill Electric Mfg. Co., Chicago, Ill.

NIKONOW, JOHN P., Member of the Russian Commission for Inspection of Artillery Orders, Bridgeport, Conn.

Recommended for transfer by the Board of Examiners January 7, 1918.

To Grade of Member

BARTON, THEOPHILUS F., Electrical Engineer, General Electric Co., Schenectady, N. Y.

McGOVERN, MAURICE T., Power & Mining Engineering Dept., General Electric Co., Schenectady, N. Y.

SEALEY, PERCY T., Operating Engineer, Illinois Northern Utilities Co., Dixon, Ill.

SMITH, CARLETON W., Electrical Engineer, Honolulu Iron Works Co., New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1918.

Anderson, A. L., Palo Alto, Cal.
Andrews, F. E., Chicago, Ill.
Bailey, R. S., Lowell, Mass.
Baker, M. P., Port Chester, N. Y.
Balyeat, R. H., Port Arthur, Texas
Batcheller, W. T., (Member), Seattle, Wash.
Bender, G. O., Ft. Wayne, Ind.
Bennis, S., (Member), New York, N. Y.
Bicking, W. L., Wilmington, Del.
Bird, F. S., (Member), Omaha, Neb.
Boisen, R. L., Ladysmith, Wis.
Boissonnault, F. L., E. Pittsburgh, Pa.
Bolling, B., Jr., (Member), Kearsage, Mich.
Boon, E. E., E. Pittsburgh, Pa.
Boyajian, A., Pittsfield, Mass.
Bracken, J. L. F., New Haven, Conn.
Brakes, J., Jr., Lima, Ohio
Braley, H. D., E. Pittsburgh, Pa.
Bressler, N. J., Reading, Pa.
Britt, E. C., Dallas, Texas
Brueck, H. L., Decatur, Ill.
Bueffel, B. H., New York, N. Y.
Bureau, E. A., Pittsburgh, Kans.
Burgett, L. S., Washington, D. C.
Canavaciol, F. E., Brooklyn, N. Y.
Carpenter, R. B., Greenville, S. C.
Cave, J., Toronto, Ont.
Chapin, S. L., Great Falls, Mont.
Colby, L. A., Pittsfield, Mass.
Coleman, H. C., E. Pittsburgh, Pa.
Conover, H. J., Buffalo, N. Y.
Corwith, H. P., New York, N. Y.
Cranston, R. W., Pittsburgh, Pa.
Cummings, B. R., Washington, D. C.
das Neves, J. G., E. Pittsburgh, Pa.
Dalrymple, F. Y., Stockton, N. Y.
Daniels, H., Boston, Mass.

Dexter, B. D., San Francisco, Cal.
Diaz, E., Rugby, Eng.
Dibble, C. McC., Chicago, Ill.
Dimmitt, C. E., Pittsburgh, Pa.
Edwards, I. P., New York, N. Y.
Egerton, H. C., (Member), New York, N. Y.
Eldred, C. P., (Member), Atlanta, Ga.
Elliott, V. D., Los Angeles, Cal.
Fink, W., Austin, Texas
Fisher, J. McF., Ford City, Ia.
France, L.E.,(Member),Cleveland,Ohio
Frederick, L. T., E. Pittsburgh, Pa.
Frye, M. A., Chicago, Ill.
Fuller, R. W., (Member), Erie, Pa.
Gardner, S. M., Bay Point, Cal.
Germain, W. A., Salt Lake City, Utah
Gould,W.M.,(Member),New York,N.Y.
Grass, S. A., Philadelphia, Pa.
Green, C. E., Richfield, Utah
Green, I. W., New York, N. Y.
Griffith, G. L., New York, N. Y.
Griffith, H. F., E. Pittsburgh, Pa.
Gudmens, H. W.,(Member), New York, N. Y.
Guildford, C. T., Pittsburgh, Pa.
Ingham, F. E., E. Pittsburgh, Pa.
Haesler, G. M., New York, N. Y.
Hall, O. T., Philadelphia, Pa.
Halsey, E. S., Camden, N. J.
Handley, H. K., Dallas, Texas
Hansen, V., Schenectady, N. Y.
Henderson, W. E., Ortonville, Minn.
Hess, E. E., Butler, Pa.
Heston, W. C., Portland, Ore.
Hilyard, E. G., Wilmington, Del.
Hoffecker, J. I., Wilmington, Del.
Hoffman, H. C., Wyoming, Pa.
Hollzer, M., San Francisco, Cal.
Hooker, C. A., Detroit, Mich.
Hopper, D. C., Chicago, Ill.
Horst, A. C., Pittsburgh, Pa.
Horth, R. S., Salt Lake City, Utah
Hutchings, J., Jr., Wilmington, Del.
Johnson, T., Jr., Washington, D. C.
Jones, G. R. Minneapolis, Minn.
Kemly, F. J., New York, N. Y.
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Klingman, L. E., Ft. Wayne, Ind.
Kovac, P., New York, N. Y.
La Forge, A. N., New York, N. Y.
Lambert, M. B., E. Pittsburgh, Pa.
Leheroff, E. G., Cincinnati, Ohio
Lewis, J. P., Birmingham, Ala.
Lindsay, R. O., Addington, N. Z.
Loos, E., Jr., E. Pittsburgh, Pa.
Lyman, O. B., Schenectady, N. Y.
Lynch, E. D., E. Pittsburgh, Pa.
Lytle, J. H., Pittsburgh, Pa.
Mann, R. C., Denver, Colo.
Marihugh, J. H., Mechanicsville, N. Y.
Martini, U., Naples, Italy
McCoy, T. F., Helena, Mont.
McGall, M. J., New York, N. Y.
McManigal, R. S., E. Pittsburgh, Pa.
Mills, G. A., (Member), Winnipeg, Can.
Mock, P. S., Philadelphia, Pa.
Moore, P. N., Pittsfield, Mass.
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Neville, J., Philadelphia, Pa.
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Newton,J.M.,(Member),Holyoke,Mass.
Ohashi, F., Shibura, Tokio, Japan
Owens, R. W., E. Pittsburgh, Pa.
Pacent,L.G.,(Member),New York,N.Y.
Packard, M. F., E. Pittsburgh, Pa.
Parks, H. F., Butte, Mont.
Parks, J. B., Philadelphia, Pa.
Patterson, W. H., E. Pittsburgh, Pa.
Patton, P. H., Omaha, Neb.
Paul, S., Balboa Heights, C. Z.
Pelley, C. G., Ithaca, N. Y.
Philpott, H., Addington, N. Z.
Phipps, T.E.,(Member),Olympia,Wash.
Plapp, E. B., Pittsburgh, Pa.
Rankin, C. S., Rumford, Maine
Reasner, G. C., Indianapolis, Ind.
Redhead, R. C., E. Pittsburgh, Pa.
Reid, W. E., New York, N. Y.
Reinicker, N. G., (Member), New York, N. Y.
Renfrew, J. M., Schenectady, N. Y.
Rose, C. F., Ruth, Nev.
Scharnberg, H. B., New-York, N. Y.
Schroeder, E. P., E. Pittsburgh, Pa.
Schwartz, W. H., E. Pittsburgh, Pa.
Scott, W. B., Miami, Florida
Scribner, G. K., Boonton, N. J.
Seabrook, H. H., Philadelphia, Pa.
Shewhart, W. A., New York, N. Y.
Smith, A. D., Auburn, N. Y.
Smith, B., E. Pittsburgh, Pa.
Smith, E. B., Honolulu, T. H.
Smith, F. W., Worcester, Mass.

Smith, G. S., Schenectady, N. Y.
Smith, R. H., (Member), Newark, N. J.
Sniffin, E. H., E. Pittsburgh, Pa.
Stephanus, A. A., E. Pittsburgh, Pa.
Stephens, A. P., E. Pittsburgh, Pa.
Stockmann, E. B., Bridgeport, Conn.
Strecker, H. L., Ampere, N. J.
Swayne, E. W., Philadelphia, Pa.
Tapscott, R. H., New York, N. Y.
Thompson, J. T., Sheridan, Ore.
Thorn, G. M., Clearfield, Pa.
Trent, H. E., E. Pittsburgh, Pa.
Truesdell, S. A., Chicago, Ill.
Vetter, N. J., New Haven, Conn.
Vogan, F. C., Philadelphia, Pa.
Vohsing, F. J., E. Pittsburgh, Pa.
Waite, R. A., Berkeley, Cal.
Waite, R. P., Preston, Idaho
Walburn, F. S., Ft. Wayne, Ind.
Waldschmidt, A., Washington, D. C.
Warner, W. H., Long Island City, N. Y.
Weaver, W. B., E. Pittsburgh, Pa.
Webb, R. S., E. Pittsburgh, Pa.
Weeks, H. E., Clinton, Mass.
Werden, R. L., New York, N. Y.
Whipple, C. C., Brooklyn, N. Y.
Whiting, D. F., New York, N. Y.
Wilson, B., (Member), Hamilton, Can.
Willson, A. R., Kansas City, Mo.
Wing, A. E., Pittsfield, Mass.
Winterroth, W. C., Chicago, Ill.
Woodcock, F. W., Salisbury, Md.
Wooten, E. A., Detroit, Mich.
Wright, F. B., Philadelphia, Pa.
Yates, C. C., New York, N. Y.
Yeager, E. S., E. Pittsburgh, Pa.
Yerbury, R. F., Passaic, N. J.
Young, F. L., Denver, Colo.
Zollinger, J. E., Chicago, Ill.
Total 133

STUDENTS ENROLLED JANUARY 11, 1918

9370 Feder, T. M., Poly. Inst. of Bklyn.
9371 Demonet, E. A., Jr., Poly. Inst. of Brooklyn
9372 Strobel, W., Jr., Poly. Inst. of Bklyn.
9373 Towhey, H. M., Villanova, Coll.
9374 Griswold, C. J., Jr., Villanova Col.
9375 Drach, E. W., Villanova Coll.
9376 Mendenhall, E., Throop Coll. of Tech.
9377 McDonald, G. R., Throop Coll. of Tech.
9378 Davis, F. L., West Virginia Univ.
9379 Yale, A. E., Worcester Poly. Inst.
9380 Winther, P. C., Jr., School of Engg. of Milwaukee
9381 Churchward, N. W., School of Engg. of Milwaukee
9382 Duling, H. B., West Virginia Univ.
9383 Olson, R. H., Univ. of Minnesota
9384 Gibbs, C. T., Univ. of Minnesota
9385 Myers, R. D., Univ. of Minnesota
9386 Hartig, H. E., Univ. of Minnesota
9387 Talbot, T. F., Univ. of Minnesota
9388 Reeve, C. H., Univ. of Minnesota
9389 Cotton, E. H., Univ. of Minnesota
9390 Heinemann, J. R., Univ. of Minn.
9391 Klass, F., Univ. of Minnesota
9392 Sander, T., Jr., Univ. of Minn.
9393 Heald, P. B., Swarthmore Coll.
9394 Simpson, A., Swarthmore Coll.
9395 Weber, W. H., Univ. of Wash.
9396 Burns, R. P., Chicago Tech. Coll.
9397 Horowitz, F., New York Electrical School
9398 Shwab, T. C., Brooklyn Poly. Inst.
9399 Witt, L. C., Rensselaer Poly. Inst.
9400 Humphrey, C. G., Rensselaer Poly. Inst.
9401 De Santis, A. J., Rensselaer Poly. Inst.
9402 Thone, J. F., Rensselaer Poly. Inst.
9403 Simons, J. A., Rensselaer Poly. Inst.
9404 Kraehn, C. E., Rensselaer Poly. Inst.
9405 Wilhelm, H. F., Rensselaer Poly. Inst.
9406 Smith, N. F., Rensselaer Poly. Inst.
9407 Ling, S. C., Rensselaer Poly. Inst.
9408 Carr, C. C., Rensselaer Poly. Inst.
9409 Wiltse, S. B., Rensselaer Poly. Inst.
9410 Reilly, F. W., Rensselaer Poly. Inst.
9411 Ashenden, H. B., Rensselaer Poly. Inst.
9412 Graves, R. C., Rensselaer Poly. Inst.
9413 Bardin, L. H., Rensselaer Poly. Inst.
9414 Mejia, J. F., Rensselaer Poly. Inst.
9415 Woods, D. E., Univ. of Texas
9416 Lawrence, M. T., Univ. of Texas
9417 Brannan, W. W., Univ. of Texas
9418 Banion, A. L., Univ. of Texas
9419 Dans, M. W., Union University
9420 Thomas, E. A., Univ. of Colorado
9421 Killian, G. L., Univ. of Colorado

9422 Love, H. A., Univ. of Colorado
9423 Stevens, K. M., Univ. of Va.
9424 Helmick, W. W., Leland Stanford, Jr., Univ.
9425 Christensen, E. W., Univ. of Minn.
9426 Jovelan, F. W., Univ. of Minn.
9427 Peterson, A. E., Univ. of Minn.
9428 Drinkall, J. F., Univ. of Minn.
9429 Zejr, G. A., Univ. of Illinois
9430 Randa, C. E., Univ. of Illinois
9431 Craigmile, R. J., Univ. of Illinois
9432 McKeever, R. E., Univ. of Illinois
9433 Foster, E. W., Cornell Univ.
9434 Stacy, T. F., Cornell Univ.

OBITUARY

JOHN HENRY GOEHST, Construction Superintendent of the Commonwealth Edison Company, President of the Federal Sign System and Treasurer of the Minerallac Electric Company, died at his home in Chicago on January 1, 1918 after a long illness. Mr. Goehst was born in Chicago on January 19, 1864 and was one of the pioneers of the electrical industry. In 1881 he went to work for H. M. Wilmarth & Bro. On December 5, 1882 Mr. Goehst secured employment with the then recently organized Western Edison Light Company of Chicago and from that time until his death he has been employed by them or their successors the Chicago Edison Company and the Commonwealth Edison Company. Mr. Goehst was a member of the Jovian Order, the Chicago Athletic Association and an Associate of the A. I. E. E.

OSBORN P. LOOMIS, electrical engineer at the works of the Newport News Shipbuilding and Dry Dock Company, died at his home on December 23, 1917. Mr. Loomis was born at Camden, N. Y. on January 20, 1862. He learned the machinists trade and commenced electrical work in Prof. Elihu Thomson's experimental workshop in 1882. He became designer for various concerns and in 1900 was made electrical engineer of the Newport News Shipbuilding Co., a position held until his death. Mr. Loomis held the grade of Member in the A. I. E. E. and was a member of the Marine Committee.

PERSONAL

C. H. ANDREWS, Assistant to President and Chief Engineer of the North Carolina Public Service Company, Greensboro, N. C., has been appointed general superintendent of Southern Utilities Company, which corporation operates electric, gas and ice properties throughout Florida, under management of the J. G. White Management Corporation. Mr. Andrews is a member of the Gas Institute and an Associate of the A. I. E. E.

PROF. O. J. FERGUSON, Head of the Electrical Engineering Department of the University of Nebraska since 1912, has been made Acting Dean of the Engineering College of that university, because of the entrance of Dean O. V. P. Stout into active military service. Prof. Ferguson is a member of the N. E. L. A., the S. P. E. E., the A. E. R. A. and Fellow of the A. I. E. E.

BURTON FRENCH, associated with the Insull Organizations for the past eighteen years in the operation of public utilities, has opened an office at 492 Continental and Commercial National Bank Building, Chicago, Ill., as Consulting Engineer, and is prepared to appraise, examine, investigate and render reports on public utility properties for financing and operation.

H. A. HORNOR will sever his connection with the New York Shipbuilding Corporation, Camden, N. J., on the first of February. Mr. Hornor has been connected with this company for seventeen years during which time he has greatly advanced the applications of electricity in the marine field. Mr. Hornor is a Fellow of the A. I. E. E. and Chairman of the Marine Committee of the Institute.

EDWARD WOODBURY, for over seventeen years with the Southern California Edison Company of Los Angeles, (formerly Pacific Light & Power Co.) has become associated with the American International Shipbuilding Corporation of Philadelphia.

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street.

Charles H. Feige
(former address)
149 West 74th St.,
New York, N. Y.

Sydney J. Hurd
(former address)
4433 Prairie Ave.,
Chicago, Ill.

Wm. P. Lewis
(former address)
Cohoes Elec. Power Co.,
Cohoes, N. Y.

Sulpen Sully
(former address)
1723 East Boulevard,
El Paso, Texas.

Ernest A. Thiele
(former address)
25 Faber St.,
Port Richmond, N. Y.

C. A. Thomsen
(former address)
Tri-State College,
Angola, Ind.

H. C. Von Rosenberg
(former address)
713 South Ave.
Wilkinsburg, Pa.

ACCESSIONS TO THE UNITED ENGINEERING SOCIETY LIBRARY

(From December 1, 1917 to January 1, 1918.)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made. These are taken either from the preface or the text of the book.

All the books listed may be consulted in the United Engineering Society Library.

A HANDBOOK FOR CANE-SUGAR MANUFACTURERS AND THEIR CHEMISTS.

By Guilford L. Spencer. 6th ed., enl. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 15+561 pp., 97 illus., 7x4 in., leather, $3.50.

Contains a review of the processes of cane-sugar manufacture, practical instruction in sugar-house control, selected methods of analysis, etc. Various typographical errors of earlier editions have been corrected and a chapter on Evaporation and Juice Heating has been added.

A PRACTISE BOOK IN ELEMENTARY METALLURGY.

By Ernest Edgar Thum. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 8+313 pp., 59 illus., 9x6 in., cloth, $2.75.

Represents the laboratory course in metallurgy given to cooperative students in mechanical, civil and electrical engineering at the University of Cincinnati. The intention has been to provide a set of detailed directions for experimental procedure in studying the metallic materials of engineering construction which would enable large numbers of students to be taught with a minimum of equipment and personal supervision.

AN INTRODUCTION TO THEORETICAL AND APPLIED COLLOID CHEMISTRY.

The World of Neglected Dimensions. By Dr. Wolfgang Ostwald. Authorized translation from the German by Dr. Martin H. Fischer. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 15+232 pp., 45 illus., 1 por., 9x6 in., cloth. $2.50.

The author has selected from his lectures before American and Canadian universities during 1913 and 1914, the five which he considers best adapted to give a general survey of modern colloid chemistry, as a pure and an applied science in a form readily intelligible to the general reader.

FLOTATION.

By T. A. Rickard and O. C. Ralston. San Francisco, Mining & Scientific

Press, 1917. 416 pp., 131 illus., 9x6 in., cloth, $3.

This book is a compilation of articles by a number of authors many of which have appeared in mining periodicals. These have been arranged and connected to form a report on recent progress in the application of the process, giving the latest available information on its technology. It discusses the history, principles and theory of flotation, costs, methods, troubles, etc., and includes a review of the litigation which has arisen.

GRAPHICS.

By H. W. Spangler. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 95 pp., 88 illus., 9x6 in., cloth, $1.25.

This work contains the substance of a series of lectures given to students at the University of Pennsylvania, covering the fundamental principles of graphics.

GREENHOUSES.

Their Construction and Equipment. By W. J. Wright. N. Y., Orange Judd Company; Lond., Kegan Paul, Trench, Trübner & Co., Ltd., 1917. 16+269 pp., 131 illus., 8x5 in., cloth, $1.60.

Intended for gardeners rather than for manufacturers of greenhouses. It gives however considerable attention to the question of their design, construction and erection, which will be useful to engineers engaged in building such structures. Costs are given.

NON-TECHNICAL CHATS ON IRON AND STEEL.

And their Application to Modern Industry. By LaVerne W. Spring. N. Y., Frederick A. Stokes Company, (copyright 1917). 11+358 pp., 294 illus., 8x6 in., cloth, $2.50.

An account of the metallurgy and mechanical working of iron and steel, based on the author's practical experience as a chemist and metallurgist in the industry. Written in popular style and very fully illustrated. Intended to provide a readable general review of modern methods for those unacquainted with the subject. Includes a list of references to other books.

PRACTICAL PYROMETRY.

The Theory, Calibration and Use of Instruments for the Measurement of High Temperatures. By Ervin S. Ferry, Glenn A. Shook, Jacob R. Collins. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 147 pp., 73 illus., 8x6 in., cloth, $1.50.

Intended for use by college students, technically trained observers who deal with processes requiring high temperature measurements, and less trained observers who may make the measurements. Includes a discussion of the theoretical principles involved and a description of the manipulative details. Experiments for purposes of instruction are also given. Contents: Standard Temperature Scales, Resistance Pyrometry, Thermoelectric Pyrometry, Radiation Pyrometry, Optical Pyrometry, Conclusion, Tables.

PROPERTIES OF STEAM AND AMMONIA.

By G. A. Goodenough. 2d ed. N. Y., John Wiley & Sons, Inc., Lond., Chapman & Hall, Ltd., 1917. 126 pp., 7 illus., 3 pl., 10x7 in., cloth, $1.25.

Tables of the properties of saturated steam and ammonia, based on new formulations which give more accurate data than those previously used to calculate such tables. Various supplementary tables are included.

RADIO COMMUNICATION.

Theory and Methods with an Appendix on Transmission over Wires. By John Mills. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1917. 205 pp., 126 illus., 7x5 in., leather.

The substance of a course of lectures given to a company of the U. S. Reserve Signal Corps troops, the members of which had had some previous training in electrical engineering. The aim has been to present the fundamental principles and methods without using any mathematics except elementary algebra or presupposing more than a limited knowledge of physics.

RECLAIMING THE ARID WEST.

The Story of the United States Reclamation Service. By George Wharton James. N. Y., Dodd, Mead and Company, 1917. 22+411 pp., 67 illus., 9x6 in., cloth, $3.50.

A popular illustrated account of the various irrigation projects undertaken by the United States Reclamation Service. The history of each project is given, together with an outline of its engineering features.

STANDARD WIRING FOR ELECTRIC LIGHT AND POWER.

As adopted by the Fire Underwriters of the United States. In accordance with the National Electrical Code, with Explanations, Illustrations and Tables Necessary for Outside and Inside Wiring and Construction for all Systems, together with a Section on House Wiring. 23d ed. By H. C. Cushing, Jr. N. Y., H. C. Cushing, Jr., 1917. 360 pp., 47 illus., 7x4 in., leather.

The object of the present book has been to standardize this work. The author has had the cooperation of the Electrical Committee of the National Fire Protection Association, the Wiring Committee of the Commercial Section of the National Electric Light Association, and the Society for Electrical Development.

Tables of Cubic Contents of Levee Embankments.

Designed by Arthur Alvord Stiles. Bulletin No. 5 of the State Reclamation Department of Texas, June 1917. Austin, State Reclamation Department, 1917. 212 pp., 1 pl., 9x6 in., leather.

Contents: Cubic Contents of Levee Embankments, Cubic Contents of Component Parts of Levee Embankments; Cubic Contents, Dimensions and Component Parts of Road Approaches to Levee Embankments.

Tables of Velocity of Water in Open Channels Derived from Kutter's Formula.

By Arthur Alvord Stiles. Bulletin No. 6 of the State Reclamation Department of Texas, August, 1917. Austin, State Reclamation Department, 1917. 130 pp., 9x6 in., leather.

These tables give the velocity in feet per second for slopes of the water surfaces, expressed in the ratio of the vertical to the horizontal, varying from 0.00055 to 0.010 and for twenty-five coefficients of roughness varying from 0.006 to 0.080.

The Chemistry of Colloids.

Part I, Kolloidchemie by Richard Zsigmondy. Trans. by Ellwood B. Spear. Part II, Industrial Colloidal Chemistry by Ellwood B. Spear, A chapter on Collodial Chemistry and Sanitation by John Foote Norton. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 288 pp., 38 illus., 9x6 in., cloth, $3.

Professor Spear has supplemented his translation of Zsigmondy's Kolloidchemie by adding several brief chapters on certain matters which are of particular interest to the technical chemist. The book is supplied throughout with numerous references to the literature on colloids. Contents: General Considerations, Classification, Properties of Colloids, Theory, Inorganic Colloids, Collodial Nonmetals, Collodial Oxides, Collodial Sulfides, Collodial Salts, Organic Colloids, Dyestuffs, Protein Bodies, Introduction to Part II, Smoke, Flue Fumes, Liquid Particles in Gases, Rubber, Tanning, Milk, Colloidal Graphite, Clays, Colloids in Sanitation.

The Electric Vehicle Hand-Book, Fifth Edition.

By H. C. Cushing, Jr. and Frank W. Smith. N. Y., H. C. Cushing, Jr., (copyright 1917). 388 pp., 172 illus., 7x4 in., flexible cloth, $2.

The object of this hand-book is to set forth as clearly as possible the fundamental principles in the operation, care and maintenance of electric vehicles, their batteries, tires, motors, controllers and accessories.

The Exporters' Directory of Japan 1917.

Tokyo, Imperial Commercial Museum of the Department of State for Agriculture and Commerce. 415+26 pp., 9x6 in., flexible cloth, $2.50.

A directory of Japanese merchants and manufacturers engaged in the export business, arranged under the lines of merchandise in which they deal. A brief description of Japan, giving considerable general information, is included.

Thomas' Register of American Manufacturers 1917.

The Largest Classified Reference Book in the World the Only One in the United States Covering All Lines 9th ed. N. Y., Thomas Publishing Company, 1917. 3900 pp., 12x10 in., cloth, $15.

Includes lists of manufacturers classified alphabetically and according to business, trade papers classified by trades, banks, boards of trade, chambers of commerce, etc., and of manufacturers' representatives. This edition, according to the publisher, contains 400 pages more than the previous one.

United States Rifles and Machine Guns.

A Detailed Account of the Methods Used in Manufacturing the Springfield, 1903 Model Service Rifle; also Descriptions of the Modified Enfield Rifle and Three Types of Machine Guns. By Fred H. Colvin and Ethan Viall. N. Y. McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Co., Ltd., 1917. 332 pp., 2347 illus., 12x9 in., cloth, $3.

Prepared at the request of the Ordnance Bureau, United States Army, to assist manufacturers in undertaking contracts. Shows the methods in use at the Springfield Armory during the fall of 1916. The machine guns included are the Lewis, the Maxim, the Vickers and the United States Machine Rifle.

EMPLOYMENT BULLETIN

Vacancies. The Institute is glad to learn of desirable vacancies from responsible sources, announcements of which will be published without charge in the BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Men Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

VACANCIES

V-318. Wanted: Men experienced in boiler house operation, equipped with Cox and Taylor stokers. Address: William B. Purdy, The Atlantic Refining Co., 3144 Passyunk Avenue. Philadelphia, Pa.

V-319. Wanted: Technical graduate for fuel economy work in connection with boiler operation, heating furnaces, and gas producers.

V-320. Technical engineer between 30 and 40 years of age, broad engineering experience, executive ability, capable of handling and organizing men. Must have detailed knowledge and experience in underground cable distribution networks, H.T. and L.T., both A.C. and D.C. One who will cooperate to secure best results. Must be able to speak Spanish. Salary $300 per month and travelling expenses. Location large power company, Barcelona, Spain.

Also an assistant electrical distribution engineer, technical training, 30 to 40 years of age with large experience in overhead and underground distribution H.T. and L.T., both A.C. and D.C. construction and operation of numerous substations. Must speak Spanish. Salary $200 per month and travelling expenses. Location large power company, Barcelona, Spain.

V-321. Wanted: Designing engineer who has had experience in design and construction of alternating current generators of large capacity. In applying state experience in detail, age, salary expected, where at present employed.

Also induction motor engineer who has had experience in design and construction of induction motors of various sizes by large manufacturing concern. In applying state salary expected, where at present employed, and experience in detail.

V-322. Recent graduates in electrical engineering desired for testing work in a large electric street railway company. Applicants with meter testing experience and now located in the vicinity of New York City preferred. State age, education, experience and salary desired.

V-323. Several positions open with the development department of a growing corporation, handling electrical precipitation processes. The work calls for technical graduates, preferably electrical, with three or four years experience, resourceful and able to carry on original works, which will be done in the vicinity of New York City. In answering give full information as to age, education, experience and salary desired.

V-324. Wanted: Mechanical draftsman as designer and checker in electric motor design. State experience, age, salary expected and give references.

V-325. Wanted immediately by the department of electrical engineering, Lafayette College, Easton, Pa., man for assistant-professorship in electrical engineering. Work will consist mostly of class-room theory and laboratory instruction with junior engineering students. Please give full information as to training and experience as well as date when earliest available.

V-326. Electrical draftsman wanted, experienced with central station and transformer sub-station layouts. State full qualifications. Good working conditions and future promise.

V-327. Wanted: A college graduate in electrical engineering with one or two years' experience for work along technical lines in a permanent position on telephone office equipment in Buffalo, N. Y. Will pay $16.00 per week for man with one year's experience and $18.00 per week for man with two years' experience. Address communications to Telephone Company, 297 Michigan St., Buffalo, N. Y.

V-328. Opportunity for several young technically trained men, preferably with some practical experience, with public service commission of New York. Salary about $90 per month to start. Please give particulars as to training, age and experience.

V-329. Wanted: Three technical graduates for steam engineering and general testing. Headquarters Pittsburgh. Work covers steel mills in Pennsylvania. Ohio, West Virginia and Indiana.

V-330. Wanted: Electrical engineer graduate with about two years' experience for permanent position with 100,000 h.p. hydroelectric development, 100 miles from Montreal. Operator not required but engineer capable of handling general technical work. Some drafting and statistical work.

V-331. Technical graduate to teach electrical subjects in a short course engineering school. One with some previous teaching experience preferred. The position will be permanent and offer good opportunities for advancement. Address Room 303, 32 Witherell Street, attention C. R. A., Detroit, Michigan.

V-332. Wanted: Graduate electrical engineer preferably with one or two years' experience, for the sale department of a company devoting its energies to the manufacture of alternating current apparatus. Correspondence confidential. Give full particulars.

V-333. Wanted: Two electrical draftsmen, in vicinity of New York. Salary $30.00 to $35.00 per week.

MEN AVAILABLE

882. Chief engineer of one of the largest tramway companies in Argentine desires change, either in South America or elsewhere. Age 38, married, ten years' experience. Languages, English, Spanish and German. Salary in Buenos Aires not less than $500 per month.

883. Electrical engineer, college graduate, age 25, single, with practical electrical and mechanical experience, desires change. Available after January 15.

884. Mechanical and electrical engineer, over twenty years' experience engineering steam plants, power transmission, electric railways and industrial service, and competent to design, construct or maintain steam and electric installations, desires responsible position as chief of power or works engineer of large factory, shipyard or public utility, or with engineering company.

885. Electrical and mechanical engineer. Have had sixteen years' experience as superintendent of interurban railways, electric light and power business; can do any kind of repair work, such as armature winding, transformer and meter repair. Am 39 years of age. Will be open for a position about February 1. Can furnish best of reference.

886. Electrical engineer with ten years' experience in design and construction of water power and steam generating stations, substations and testing of electrical equipment. Considerable experience in transmission line calculations. College graduate. American. Age 35. Will locate any place. Salary $200 to $300 per month.

887. Electrical engineer, fifteen years in the manufacture, testing, repair and installation of electrical machinery, transformers and turbine alternators, desires position as construction superintendent, chief operating, or maintenance engineer. Location in or near Chicago desirable. Will consider change on one month's notice to present employers. Married. Age 34. Salary $3000.

888. Electrical and mechanical engineer, technical graduate, age 35, ten years' experience in the design, building and testing of polyphase induction motors in sizes from ½ to 500 h.p., desires position in charge of design, either in redesign of standard line or in design of new line. Salary $3000.

889. Young man with eighteen years' electrical experience desires to connect with engineering company engaged in designing and installing industrial equipment. Now hold responsible position in the electrical department of an automobile manufacturing company. A desire to engage in a field where I can develop more along engineering lines is the only reason for seeking a change.

890. Expert designer of A.C. and D.C. power machinery desires change. Familiar with manufacturing and prefers position as engineer-superintendent of plant or factory manufacturing electrical machinery. Age 38. Available on two months' notice. Salary $5000 to $6000.

891. Manufacturing superintendent with wide experience in light and heavy quantity production of mechanical and electrical work, in the design, installation and maintenance of modern factories and equipment; handling 200 to 500 skilled and unskilled employees; technically educated; now employed similar capacity, desires change to shop requiring increased production.

892. Sales engineer, ten years' experience, technical education. Expert knowledge motors, generators and traveling cranes. Have sold gas engines and general electrical and mechanical equipment. Location no object. Pacific Coast or Southwest

preferred. Willing to travel. Salary $3000. Age 28. Married.

893. Electrical engineer, technical graduate. twelve years' experience in power station and substation construction and design, also industrial power applications, transmission and lighting work. At present employed but available on reasonable notice.

894. Executive, mechanical-electrical engineer desires responsible position as manager or superintendent. Experience includes foundry, machine shop, assembling, design, estimates, construction, appraisal, maintenance of equipment, electrician, and power generation. Experienced in Cottrell process of electrical precipitation. At present employed. American. Graduate M. E. Married. Salary $3000 to $4000.

895. Technical man, age 34, desires new position of responsibility. Three years with G. E. Co., steam and electric test, motor and power salesman. Five years central station work, superintendent of 25,000 kw. steam and hydro system, construction and design of high voltage sub-stations. In charge of power sales for industrial territory with 500,000 population.

896. Graduate electrical engineer. Six years' experience. General Electric test, surveys, estimates, design and construction of hydraulic power plants and appraisals of electric railway, power and light properties. Desires designing or operating position with established company in hydro-electric work. Married. Age 28. Reason for change present locality undesirable.

897. Electrical and mechanical engineer, fifteen years with large manufacturing concern. Apprentice to district office manager. Ten years consulting engineer with own practice, designing, constructing and operating power plants, distribution systems, etc. Particularly successful handling men. Details of experience and reasons for change if required. Minimum salary $3500.

898. Assistant professor of electrical engineering in large middle western university, 36 years of age, desires position as head professor, while at the age at which he can do his best work. Author well-known textbook; member A. I. E. E., N. E. L. A. Ten years teaching. Five years commercial experience. Some consulting and testing experience.

899. Chief electrical draftsman with wide experience in design and construction of power stations, substations and outdoor switch structures of voltages up to 70,000. At present holds position of chief electrical draftsman. Technical training. Good correspondent. Married. Age 32. Salary $2000. New York City only.

900. Graduate electrical engineer experienced in central station operation and distribution, desires position as manager or superintendent. Also seven years' experience as engineer of construction and maintenance of underground system. Married. Age 38.

901. Purchasing agent, with executive experience, technical education, electrical engineering; shop and selling experience. Seven years as general engineer and industrial plants purchasing agent. Will consider change on month's notice to present employers. Married. Age 34. Salary $3000.

902. Electrical engineer, technical graduate, age 34, eleven years of operating and extensive engineering experience with a large central station company. Available for position as designing electrical engineer with a consulting engineer, manufacturing concern, or central station company. Salary $3000.

903. Technical graduate, fourteen years' experience installing and operating steam power plant machinery. Now hold position as mechanical superintendent of a government plant where have charge of steam electric power plant, repair shop and installation of new machinery. Consider executive position in central station or manufacturing plant. Salary $2500.

904. University graduate (33) with ten years' electrical and mechanical experience General Electric test, hydro-electric operation, power station design and appraisal work, wishes responsible position with public service corporation or electrical department of large industrial plant. Salary $3000.

905. Electrical and Mechanical Engineer, technical graduate, three years in development of large manufacturing company, and four years successful teaching in large university. Good organizer and executive, 30 years old, married. Would accept position in development or efficiency department, or college professorship. Salary not less than $2,500. Available between April and June.

906. Electrical Engineering Graduate, 33 years of age, desires position on government work, or as instructor in electrical engineering. Experience in steel manufacture, power plant construction, testing, engineering and selling, and in application of electrical apparatus. Instructor in mathematics and electrical engineering. Latest salary $2,100.

OFFICERS AND BOARD OF DIRECTORS, 1917-1918.

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(Term expires July 31, 1918)
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(Term expires July 31, 1918)
JOHN J. CARTY

(Term expires July 31, 1919)
H. W. BUCK

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(Term expires July 31, 1918)

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(Term expires July 31, 1918)
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JOHN B. TAYLOR
HAROLD PENDER

(Term expires July 31, 1919)
C. E. SKINNER
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(Term expires July 31, 1920)
CHARLES S. RUFFNER
CHARLES ROBBINS
E. H. MARTINDALE

(Term expires July 31, 1921)
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(Term expires July 31, 1918)

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52 Broadway, New York.

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*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-92.
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
*LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-02.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
*HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.
JOHN J. CARTY, 1915-16.
H. W. BUCK, 1916-17

*Deceased.

INSTITUTE COMMITTEES.

Revised to January 1, 1918.

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General Electric Company, Schenectady, N. Y.
H. W. Buck, Harold Pender,
N. A. Carle, L. T. Robinson,
George A. Hamilton, C. E. Skinner.

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Public Service Electric Company, Newark, N. J.
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W. I. Slichter,
and the chairmen of the technical committees

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Henry H. Norris, C. E. Skinner.

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Johnston Livingston, C. E. Skinner,
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F. L. Rhodes, W. I. Slichter.

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General Electric Company, West Lynn, Mass.
P. H. Daggett, Vice-Chairman
John B. Fisken, H. W. Flashman,
A. M. Schoen,
and the chairmen of all Institute Sections, *ex-officio*.

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(Sub-Committee of Sections Committee.)
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W. E. and M. Company, 165 Broadway, N. Y.
T. F. Barton, Wills MacLachlan,
H. Goodwin, Jr., H. R. Woodrow.
and the chairmen of local membership committees.

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165 Broadway, New York.
H. W. Buck, P. Junkersfeld,
N. A. Carle, John W. Lieb,
John J. Carty, E. W. Rice, Jr.,
C. E. Skinner.

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Public Service Electric Company, Newark, N. J.
A. S. McAllister, F. L. Hutchinson.

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Frederick Bedell, H. M. Hobart,
Joseph Bijur, Henry D. James,
L. F. Blume, P. Junkersfeld,
James Burke, A. E. Kennelly,
G. A. Burnham, G. L. Knight,
N. A. Carle, F. A. Laws,
P. H. Chase, A. S. McAllister,
E. J. Cheney, W. L. Merrill,
H. H. Clark, Harold S. Osborne,
E. H. Colpitts, Charles Robbins,
F. P. Cox, L. T. Robinson,
William A. Del Mar, C. H. Sharp,
A. M. Dudley, C. E. Skinner,
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H. W. Fisher, John B. Taylor,
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Gano Dunn, Charles F. Scott,
H. M. Hobart, Clayton H. Sharp,
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EDISON MEDAL COMMITTEE.

Appointed by the President for terms of five years.

Term expires July 31, 1918.
H. W. Buck, F. A. Scheffler,
J. Franklin Stevens.

Term expires July 31, 1919.
Charles F. Brush, C. C. Chesney.
N. W. Storer,

Term expires July 31, 1920.
Carl Hering, Chairman, Harris J. Ryan,
Robert Lindsay.

Term expires July 31, 1921.
W. C. L. Eglin, Bancroft Gherardi,
E. W. Rice, Jr.

Term expires July 31, 1922.
C. A. Adams, L. A. Ferguson,
S. W. Stratton.

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1918.
L. T. Robinson, Harold Pender,
C. E. Skinner.

Term expires July 31, 1919.
B. A. Behrend, Frederick Bedell,
A. S. McAllister.

Ex-Officio.
E. W. Rice, Jr., President,
George A. Hamilton, Treasurer,
F. L. Hutchinson, Secretary

TECHNICAL COMMITTEES.

Revised to January 1, 1918.

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Hamilton Court, 39th and Chestnut Streets, Philadelphia, Pa.
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Sperry Gyroscope Company,
Manhattan Bridge Plaza, Brooklyn, N. Y.

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General Electric Company, Schenectady, N.Y.

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Cornell University, Ithaca, N. Y.

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104 East 32nd St., New York.

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Union College, Schenectady, N. Y.

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John J. Carty. E. W. Rice, Jr

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Samuel Sheldon, Calvert Townley.
L. T. Robinson.

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Edward D. Adams, W. I. Slichter,
F. L. Hutchinson.

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The chairman of the Institute's Code Committee.

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Edward Caldwell.

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F. B. Jewett.

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John H. Finney Charles W. Stone,
Calvert Townley.

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Farley Osgood, Percy H. Thomas.

AMERICAN COMMITTEE ON ELECTROLYSIS.

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Paul Winsor.

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E. W. Rice, Jr., C. E. Skinner.
N. A. Carle,

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H. W. Buck, C. A. Adams.

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John Price Jackson, Charles F. Scott.

LOCAL HONORARY SECRETARIES.

Guido Semenza, N. 10 Via S. Radegonda, Milan, Italy.

Robert Julian Scott, Christchurch, New Zealand.

T. P. Strickland, N. S. W. Government Railways Sydney, N. S. W.

W. G. T. Goodman, Adelaide, South Australia.

James S. Fitzmaurice, Perth, West Australia.

L. A. Herdt, McGill Univ., Montreal, Que.

Henry Graftio, Ministry of Ways of Communication, Petrograd, Russia.

A. S. Garfield, 45 Boulevard Beausejour Paris 16 E. France.

Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.

John W. Kirkland, Johannesburg, South Africa.

LIST OF SECTIONS

Revised to January 1, 1918

Name and when Organized	Chairman	Secretary
Atlanta................Jan. 19, '04	A. M. Schoen	Thomas C. Taliaferro, S. E. Underwriters Ass'n., Atlanta, Ga.
Baltimore.............Dec. 16, '04	J. B. Whitehead	L.M.Potts,Industrial Bldg.,Baltimore,Md.
Boston................Feb. 13, '03	H. M. Hope	Ira M. Cushing,84 State St.,Boston,Mass.
Chicago......................1893	Wm. J. Crumpton	C.A.Keller,Edison Building, Chicago, Ill.
Cleveland.............Sept. 27, '07	C. N. Rakestraw	C. S. Ripley, 711 Williamson Building, Cleveland, Ohio.
Denver...............May 18, '15	Norman Read	Robert B. Bonney, 806 Telephone Building, Denver, Colo.
Detroit-Ann Arbor......Jan. 13, '11	H. H. Higbie	H. J. Wyckoff, Detroit Edison Company, Detroit, Mich.
Erie..................Jan. 11, '18		
Fort Wayne...........Aug. 14, '08	J. J. Kline	R. B. Roberts, G. E. Co., Fort Wayne,Ind.
Indianapolis-Lafayette..Jan. 12, '12	H. O. Garman	E. L. Carter, Public Service Commission of Indiana,State House, Indianapolis,Ind.
Ithaca................Oct. 15, '02	F. Bedell	Alexander Gray,CornellUniv.,Ithaca,N.Y.
Kansas City, Mo.......Apr. 14, '16	W. F. Barnes	W. F. Barnes, 1012 Baltimore Ave., Kansas City, Mo.
Los Angeles.......... May 19, '08	Don Morgan	A. W. Nye, University of Southern California, Los Angeles, Cal.
Lynn.................Aug. 22, '11	J. M. Davis	R. D. Thomson, General Electric Company, West Lynn, Mass.
Madison..............Jan. 8, '09	J. R. Price	L. E. A. Kelso, University of Wisconsin, Madison, Wis.
Mexico...............Dec. 13, '07		
Milwaukee............Feb. 11, '10	Arthur Simon	Soren H. Mortensen, Allis-Chalmers Mfg. Co., West Allis, Wis.
Minnesota.............Apr. 7, '02	F. W. Springer	A. B. King, Electric Machinery Company, Minneapolis, Minn.
Panama...............Oct. 10, '13	C. J. Embree	William F. Connell, Balboa Heights, C. Z.
Philadelphia...........Feb. 18, '03	Nathan Hayward	H. Mouradian, Bell Telephone Co. of Penna., Philadelphia, Pa.
Pittsburgh.............Oct. 13, '02	F. E. Wynne	G. M. Baker, G. E. Co., Oliver Building, Pittsburgh, Pa.
Pittsfield.............Mar. 25, '04	F. F. Brand	E. H. Branson, General Electric Company, Pittsfield, Mass.
Portland, Ore..........May 18, '09	E. D. Searing	R. M. Boykin, North Coast Power Co., Portland, Oregon.
Rochester.............Oct. 9, '14	Frank C. Taylor	C. T. Wallis, 138 Fairview Avenue, Rochester, N. Y.
St. Louis..............Jan. 14, '03	H. W. Eales	Benjamin F. Thomas, Jr., 3869 Park Ave., St. Louis, Mo.
San Francisco..........Dec. 23, '04	L. R. Jorgensen	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady...........Jan. 26, '03	W. L. Upson	L. F. Millham, General Electric Company, Schenectady, N. Y.
Seattle...............Jan. 19, '04	J. Harisberger	G. Dunbar, Seattle Light and Power System, Seattle, Wash.
Spokane..............Feb. 14, '13	Charles A. Lund	J. E. E. Royer, Washington Water Power Company, Spokane, Wash.
Toledo ....June 3, '07	W. E. Richards	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio.
Toronto..............Sept. 30, '03	William G.Gordon	Ernest V. Pannell, 60 Front Street, West, Toronto, Ont.
Utah Section...........Mar. 9, '17	A. S. Peters	H. T. Plumb, Newhouse Bldg., Salt Lake City, Utah.
Urbana...............Nov. 25, '02	L. V. James	A. R. Knight, Univ of Illinois, Urbana,Ill.
Vancouver.............Aug. 22, '11	R. F. Hayward	T. H. Crosby, Canadian Westinghouse Co. Vancouver, B. C
Washington, D. C.......Apr. 9, '03	Paul G. Agnew	J. Ernest Smith, McKinley Manual Training School, Washington, D. C.

Total 34

LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas......Nov. 12, '09	L. E. Tighe	F. V. Murrah, College Station, Tex.
Alabama Poly. Inst......Nov. 10, '16	W. W. Hill	J. A. Douglas, P.O. Box 190, Auburn, Ala.
Alabama, Univ. of......Dec. 11, '14		
Arkansas, Univ. of......Mar. 25, '04	E. P. O'Neal	J. C. Douthit, University of Arkansas, Fayetteville, Ark.
Armour Institute.......Feb. 26, '04	R A. Newlander	A. A. Hofgren, 7542 So. Chicago Ave., Chicago, Ill.
Brooklyn Poly. Inst......Jan. 14, '16	G. Hotchkiss	E. A. Demonet, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University.....May 17, '10	C. W. Mason	Leon H. Nol', Bucknell University, Lewisburg, Pa.
California, Univ. of.....Feb. 9, '12	A. J. Swank	G. F. Teale, University of California, Berkeley, Cal.
Carnegie Inst. of Tech...May 18, '15	W. F. Eames	B. C. Dennison, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of.....Apr. 10, '08		C. B. Hoffman, University of Cincinnati, Cincinnati, Ohio
Clarkson Col. of Tech....Dec. 10, '15	R. H. Hoyt	E. S. Parks, Clarkson College of Technology, Potsdam, N. Y.
Clemson AgriculturalCol.Nov. 8, '12		
Colorado State Agricultural College.........Feb. 11, '10	R. C. Richards	W. A. Stallings, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized		Chairman	Secretary
Colorado, Univ. of	Dec. 16, '04	Robert Newman	William N. Gittings, University of Colorado, Boulder, Colo.
Georgia School of Technology	June 25, '14	Reese Mills	Graham Granger, Georgia School of Technology, Atlanta, Ga.
Highland Park College	Oct. 11, '12		
Idaho, Univ of	June 25, '14		
Iowa, Univ. of	May 18, '09	V. E. Pearson	L.J.Corbett, Univ.of Idaho, Moscow, Idaho.
Kansas State Agr. Col.	Jan. 10, '08	L. N. Miller	I. H. Russell, Kansas State Agri. Col., Manhattan, Kansas.
Kansas Univ. of	Mar. 18, '08	Clarence Lynn	Robert W. Warner, 1428 Tennessee Street, Lawrence, Mass.
Kentucky, State Univ. of	Oct. 14, '10	J. M. Hedges, Jr.	Robert M. Davis, State University of Kentucky, Lexington, Ky.
Lafayette College	Apr. 5, '12	Harry C. Hartung	William Lash Lipps, 633 Parsons, Easton, Pa.
Lehigh University	Oct. 15, '02	R. H. Lindsay	R. D. Bean, 40 N. 7th Ave., Bethlehem, Pa.
Lewis Institute	Nov. 8, '07	Bernard Slater	Edwin, Verrall, Lewis Institute, Chicago.
Maine Univ. of	Dec. 26, '06		
Massachusetts Inst. of Tech.	Apr. 13, '17	Wm. H. Costello	George A. Elz, Massachusetts Institute of Tech., Cambridge, Mass.
Michigan, Univ. of	Mar. 25, '04	W. R. Harvey	T. W. Conant, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of	May 16, '16	Russell Ross	Ray McKibben, University of Minnesota, Minneapolis, Minn.
Missouri Univ. of	Jan. 10, '03	A. C. Lanier	D. P. Savant, University of Missouri, Columbia, Mo.
Montana State Col.	May 21, '07	Roy C. Hagen	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Olin J. Ferguson	Oskar E. Edison, University of Nebraska, Lincoln, Nebraska.
North Carolina Col. of Agr. and Mech. Arts	Feb. 11, '10	F. N. Bell	Landon C. Flournoy, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
North Carolina, Univ. of	Oct. 9, '14		
North Dakota, Univ. of	Feb. 15, '17	D. F. McConnell	Roy A. Wehe, University, N. D.
Norwich University	June 28, '16		
Ohio Northern Univ	Feb. 9, '12	W. F. Parsons	A. J. Ferlic, 718 N. Main Street Ada, Ohio.
Ohio State University	Dec. 20, '02	E. S. Gunn	T. D. Robb, 124 West 10th Ave., Columbus, Ohio.
Oklahoma Agricultural and Mech. Col.	Oct. 13, '11		
Oklahoma, Univ. of	Oct. 11, '12	C. T. Hughes	C. H. Whitwell, University of Oklahoma, Norman, Okla.
Oregon Agr. Col.	Mar. 24, '08	L. Happold	Lawrence Fudge, Oregon Agri. College, Corvallis, Ore.
Penn. State College	Dec. 20, '02	H. A. Billig	P. J. F. Derr, State College, Pa.
Pittsburgh, Univ. of	Feb. 26, '14		
Purdue University	Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Queen's University (Ont.)	Jan. 11, '18		
Rensselaer Poly. Inst.	Nov. 12, '09	W. J. Williams	Leroy C. Witt, Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst.	Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terra Haute, Ind.
Stanford Univ.	Dec. 13, '07	C. H. Suydam	Frank Miller, Stanford University, Cal.
Syracuse Univ.	Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of	Feb. 14, '08		
Throop College of Technology	Oct. 14, '10		
Virginia Polytechnic Institute	Jan. 8, '15	Baxter McIntosh	J. A. Carr, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of	Feb. 9, '12	Charles Henderson	J.Arthur Evans, University, Va.
Wash., State Col. of	Dec. 13, '07	B. Benz	Clarence E. Guse, 393 College Sta., Pullman, Wash.
Washington Univ.	Feb. 5, '04	R.W. MacDonald	Walter J. Skrainska, Washington University, St. Louis, Mo.
Washington, Univ. of	Dec. 13, '12	L. P. Kongsted	L. M. Lubcke, University of Washington, Seattle, Wash.
West Virginia Univ.	Nov. 13, '14		
Worcester Poly. Inst.	Mar. 25, '04	B. Luther	N. L. Towle, Worcester Polytechnic Institute, Worcester, Mass.
Yale University	Oct. 13, '11	Brian O'Brien	G. P. Nevitt, 249 Park Street, New Haven, Conn.

Total 58

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RATING AND SELECTION OF OIL CIRCUIT BREAKERS

BY E. M. HEWLETT, J. M. MAHONEY AND G. A. BURNHAM

ABSTRACT OF PAPER

On account of the variable conditions in systems on which circuit breakers are used, it is impossible to give a simple rule which will cover the selection of circuit breakers for all cases. The authors discuss the interpretations of the A. I. E. E. Standardization Rules covering the rating of oil circuit breakers and consider the variable factors which are involved in the selection of circuit breakers for various systems. A method is suggested whereby short-circuit characteristics of various systems can be used for determining the proper selection of oil circuit breakers for average systems. The method does not apply to very large systems or unusual conditions.

THERE IS an increasing demand from engineers and operators for a more uniform statement from the various manufacturers with reference to the rating and recommended selection of electrical protective equipment. It appears that simple concise statements might easily be made that would convey definitely the desired information, but there are so many variables which enter into the selection that a simple statement to cover all cases is impossible.

The object of this paper is, (1) to discuss the interpretations of the A. I. E. E. rules covering the rating of oil circuit breakers, (2) to discuss the factors involved in the proper selection of oil circuit breakers, and (3) to suggest average system short-circuit characteristics which can be used for selecting oil circuit breakers for certain systems.

It is hoped that the interpretation given and the date proposed for oil circuit breaker selection will meet with the approval of those persons interested in this problem or give rise to suggestions leading to improvement.

The subject has received careful consideration by the Standards Committees of the American Institute of Electrical Engineers and several papers on this subject[1] have been presented

1. Rating of Oil Circuit Breakers, by E. M. Hewlett, TRANSACTIONS, A. I. E. E., 1916; Rupturing capacities of Oil Circuit Breakers, by S. Q. Hayes, TRANSACTIONS, A. I. E. E., 1916; Rating of Oil Circuit Breakers, by G. A. Burnham, TRANSACTIONS, A. I. E. E., 1913.

Manuscript of this paper was received January 11, 1918; released for publication on January 11, 1918.

to the Institute, all of which have resulted in bringing about a clearer understanding of the various expressions and methods used in connection with the rating of this class of equipment.

Circuit breakers are classified according to their rated pressure, rated current, rated frequency and interrupting capacity.

Systems may be classified according to their normal operating pressure, normal current, normal frequency and current transients.

The *rated pressure* (voltage) of a circuit breaker is the greatest normal pressure in r.m.s. volts between any two wires of any circuit to which the breaker should be connected.

The Standardization Rules of the American Institute of Electrical Engineers require that oil circuit breakers for voltages above 600 volts withstand a dielectric test[2] of 2.25 times rated pressure plus 2000 volts for 60 seconds. Although not stated in the rules we infer that it contemplates a test with the apparatus under dry conditions.

The *normal operating pressure* of a system is the greatest pressure in r.m.s. volts ordinarily maintained between any two conductors.

The rated current of a circuit breaker as defined by the A. I. E. E.[3] is "the normal r.m.s. current which it is designed to carry." This rating is covered by the following rule.[4]

"Temperature Tests—Rated Current at rated frequency shall be applied continuously until the temperature becomes constant. The maximum temperatures of the various parts shall not exceed the following when the ambient temperature of reference is 40 deg. cent.:

Contacts in air.......................60 deg. cent.[5]
Oil and contacts therein.............70 deg. cent.
Coils (See sections 376-379 incl.)[6]
Other parts (see section 392)[7]

2. Rule 755. June 1917, supplement to A.I.E.E., Standardization Rules.

3. Rule 752, June 1917, Supplement to A.I.E.E. Standardization Rules.

4. Rule 754, June 1917, Supplement to A.I.E.E. Standardization Rules.

5. Contacts in air may be subjected to an ultimate temperature at 70 deg. cent. for periods of short duration.

6. The rules referred to herein, limit the maximum permissible temperature rise, of coils to temperatures determined by the insulating materials used.

7. The rule referred to above reads in part as follows: "All parts of electrical machinery other than those whose temperature affects the temperature of the insulating material may be operated at such temperatures as shall not be injurious in any other respects."

"The Institute recognizes the inherent decrease in capacity of switch and circuit-breaker contacts in air, due to oxidization of the contact surfaces. The rating of air switches and circuit breakers is, therefore, based on sufficient maintenance to keep the temperature within the specified limits."

The *normal current* in a circuit of an electrical system is the rated current in r.m.s. amperes for which that circuit is designed.

The actual current may vary through wide limits from day to day and at different seasons of the year. The upper limit for continuous operation or the rated current is, however, fixed by the capacity of the conductors as determined by the maximum allowable temperature at which the conductors and their insulation may be operated.

The *interrupting* (rupturing) *capacity* of a circuit breaker as specified by the Standardization Rules[8] of the American Institute of Electrical Engineers is:

"——the highest r.m.s. current at normal voltage which the device can interrupt under prescribed conditions at stated intervals a specified number of times."

It is recognized that factors anticipated in the above rule as the "prescribed conditions" may affect the interrupting capacity of the breaker. Such factors are discussed under the section: "Present Interrupting Capacity Rating."

The "stated intervals" and "specified number of times" at a given current and pressure determine the *duty* imposed upon the breaker. The breaker interrupting capacities in r.m.s. amperes published by various manufacturers are based on an assumed duty, *i.e.*, that the breaker will interrupt its rated r.m.s. current two times at a two minute interval and then be in condition to be closed and carry its rated current until it is practicable to inspect it and make necessary adjustments.

The duty, including a statement of the "prescribed conditions" therefore, places a limit on the interrupting capacity of a breaker and any change in duty or prescribed conditions will necessarily affect the rated interrupting capacity.

Previous Interrupting Capacity Ratings

It has been the practise in the past to state the interrupting capacity of circuit breakers in terms of the total alternator capacity in kv-a. at a specified reactance. In rating a circuit

8. Rule 753, June 1917, Supplement to A. I. E. E. Standardization Rules.

breaker in these terms, consideration was given to the short-circuit characteristics of the machines together with the characteristics of the circuit breakers and relays.

The "arc kv-a." ratings as previously listed were derived by multiplying the interrupting capacities in amperes by an assumed value of pressure. This assumed value was considered as the probable pressure that would be re-established on the bus immediately after the short circuit was cleared or that occurring during the clearing. The "arc kv-a." rating, based on the assumption that the re-established bus pressure will be normal, can be obtained for three phase circuits by multiplying the interrupting capacity of the breaker in amperes by the normal pressure in volts of the circuit to which it is connected, and by the factor 1.73.

It is to be noted that the interrupting capacity rating specified by the A. I. E. E. in r.m.s. current anticipates normal pressure to be re-established. Systems having characteristics such that the re-established pressure during short circuit will be higher than normal, will require a larger breaker.

As power stations have increased in capacity, and transmission and distribution net works extended, considerable reactance is introduced between the alternators and the point of short circuit which limits the current appreciably, and the total alternator capacity is no longer a measure of the severity of the short circuit. Service considerations are becoming more severe and larger, and more expensive circuit breakers are required. A method of rating circuit breakers that will allow of more accurate selection for a wide range of conditions is desirable.

Present Interrupting Capacity Rating

The rating of a circuit breaker in r.m.s. current interrupted at normal operating pressure simplifies the selection of a proper breaker for a given service condition. Such a rating makes comparative tests possible if a sufficient amount of power is available.

In the A. I. E. E. rule establishing this rating it is qualified by the words "prescribed conditions". It is generally recognized, indicated by test and by the operation of circuit breakers in service; that the power factor and the stored electrostatic and magnetic energy of the system are among the conditions affecting the interrupting capacity at a given r.m.s. current. During the current-opening periods an arc is established, and

the current and voltage relations during this period are much more complicated than the simple phase-angle relation covered by the statement of power factor. Furthermore, the arc may be re-established under transient voltage conditions, still further complicating the phenomena. The theoretical and empirical data available on the effect of these conditions on the work done by the breaker is not at present adequate for the authors to prescribe any particular power factor for test, or to suggest any method for general use, to take into account the power factor and energy storage characteristics for all systems. These factors are of special importance when a breaker of relatively small interrupting capacity is connected to a large system in such a way that the breaker may afford the only outlet for the stored energy of the system. Such influences, while extremely difficult to take into account, will not differ widely in average systems. They are taken into account in a general way in the factor of safety employed in the rating of a breaker and their effects need not be considered in ordinary individual problems.

Selection of breakers for unusual conditions, large systems, or those involving large investment, should be checked with the manufacturers.

For average systems, a determination of the r.m.s. current that will flow at the instant the contacts part, irrespective of power factor or circuit conditions, will enable one to select the proper circuit breaker.

Determination of Short-Circuit Current

In order to determine the r.m.s. current that the circuit breaker will be required to open, an analysis of short-circuit phenomena on an alternating-current net work is necessary. and it may be desirable to call attention to some of the conditions under which circuit breakers may be called upon to function.

Short circuiting a system at any point permits an abnormal current to flow immediately in that system. The amount and persistency of this current rush depend upon the characteristics of the synchronous apparatus connected to the system at the time, and upon the impedance in circuit between the synchronous apparatus and the point of short circuit. The value of r.m.s. current which the circuit breaker will be called upon to interrupt, will depend upon the length of time that elapses between the start of short circuit and the parting of the contacts as will be seen from the following analysis of short circuits.

The greatest transient disturbance of the system which can occur at the point of application of the circuit breaker when the system is short circuited, governs the selection of a suitable breaker. A diagram showing the current flowing in one phase of the external circuit when a system is short circuited under ordinary operating conditions, is shown in Fig. 1. In this diagram O is the origin of the co-ordinates and is taken at the instant at which the short circuit occurs. $O X$ is the axis of abscissae and the abscissae represent time. $O Y$ is the axis of ordinates and the ordinates represent current. $C D$ is a curve passing through the maxima of the wave of the total current and $E F$ is a curve passing through the minima. $A B$ is a curve

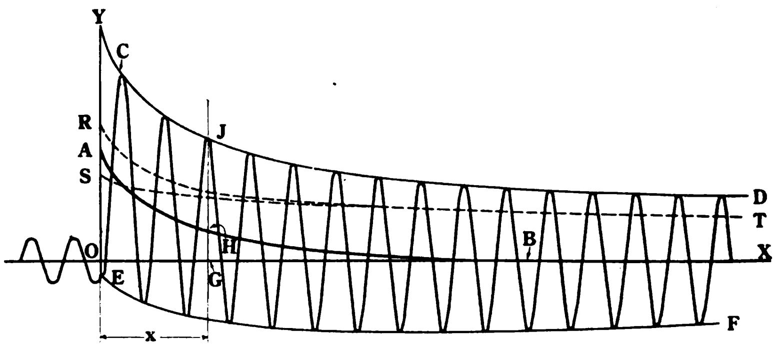

FIG. 1

Generator characteristics—illustration of behavior of generator current when short circuited from full load at 0.8 power factor

which cuts the vertical everywhere midway between $C D$ and $E F$.

The wave of total current whose crests lie along curve C D and $E F$ and whose ordinates are measured from the axis $O X$ may be regarded as having two components, namely,

1. A direct component
2. An alternating component.

The direct component is represented at any time by the ordinate to the curve $A B$ or at the time x by the ordinate $G H$.

The alternating component is a wave whose crest value at any time is the difference between the ordinates to the curves $C D$ and $A B$. This difference, at the time x, has the value $H J$. The r.m.s. values of this alternating component are shown on curve $S t$. At any instant this component is considered to have the same r.m.s. value as an alternating wave of constant ampli-

tude whose crest value is represented by one half the distance between curves $C D$ and $E F$ at that instant.

The r.m.s. value of the total current wave under short circuit at any instant is the square root of the sum of the squares of the value of the *direct component* and the *effective* value of the *alternating component* at that instant. This r.m.s. value of the total current at the time of parting of the circuit-breaker contacts is used in making circuit-breaker applications.

The r.m.s. current at any point of a system under short circuit conditions is affected by the following factors.

1. The total kv-a. reactance and transient characteristics of the synchronous machines connected to the system.

2. Number, reactance, resistance, capacitance and arrangement of all circuits over which power can be supplied to the point of short circuit.

3. The kv-a., arrangement, resistance, reactance and capacitance of all reactors and transformers through which power can be supplied to the point of short circuit.

4. Contact resistance at the short circuit.

5. The nature of the short circuit, whether single-phase or multiphase.

6. The kv-a. and power factor of the load being carried at the time of the short circuit.

7. The point of the pressure wave at which the short circuit was established.

8. The use of automatic voltage regulators.

The short-circuit transient for systems may be determined by test, by calculation or, less closely, by assumption. Obviously, the determination by test for all circuits of a large system is expensive and involves considerable time and interruption to service. This will be practicable in but few cases. The determination by calculation is also a matter of considerable labor but is feasible if only the important factors listed above are considered. Practical approximate selection, sufficiently accurate for many cases can be made by using only reactance and an accepted group of time current decrement curves.

Suggested decrement curves are shown on Figs. 2 and 3 and their ordinates on Table I.

These curves are based on the following assumptions: Transient characteristics for alternators of normal design determined from oscillograph tests: That the effect of capacitance and resistance is neglected: That the contact resistance at short

circuit is zero: That the alternator is carrying full load 80 per cent power factor: That the short circuit was established at the point of the pressure wave corresponding to maximum possible

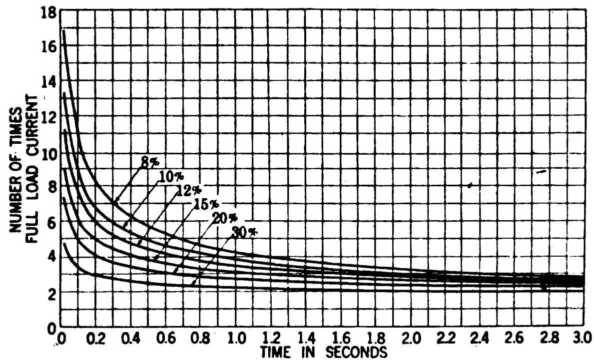

FIG. 2

System short circuit characteristics—8, 10, 12, 15, 20 and 30 per cent total reactance based on total kv-a. rating of synchronous machines

Time current curves—r. m. s. current in terms of total full-load current of machines—initial full load at 0.8 power factor assumed

instantaneous current: That no automatic voltage regulators are used.

These curves differ from those that have been usually considered in the past for two reasons: first, r.m.s. values are used

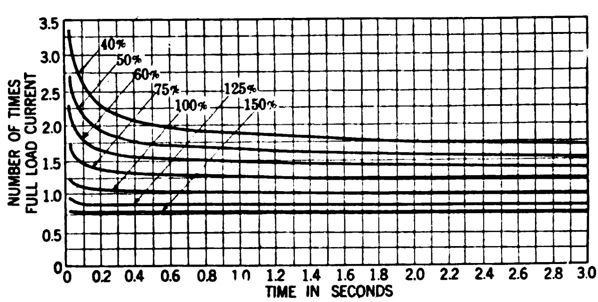

FIG. 3

System short-circuit characteristics—40, 50, 60, 75, 100, 125 and 150 per cent total reactance based on total kv-a. rating of synchronous machines

Time-current curves—r. m. s. current in terms of total full-load current of machines—initial full load at 0.8 power factor assumed

instead of peak values; and second, the effect of the increased flux existing under the load condition assumed has been taken into account.

The effect of using r.m.s. values instead of peak values is to

TABLE I—SHORT CIRCUIT CURRENT FACTORS.

Reactance*	8%	10%	12%	15%	20%	30%	40%	50%	60%	75%	100%	125%	150%
Elasped time in seconds from start of short circuit.	Current Factors expressed as number of times full load current.†												
0.05	13.91	11.16	9.59	7.68	6.04	4.03	3.01	2.40	2.00	1.58	1.17	0.92	0.77
0.08	11.78	9.54	8.25	6.66	5.27	3.59	2.74	2.21	1.86	1.50	1.13	0.90	0.76
0.10	10.94	8.89	7.68	6.23	4.97	3.41	2.63	2.13	1.81	1.46	1.11	0.89	0.76
0.15	9.16	7.54	6.57	5.40	4.38	3.08	2.42	2.00	1.71	1.41	1.09	0.89	0.76
0.20	8.24	6.80	5.97	4.95	4.06	2.92	2.30	1.92	1.66	1.38	1.08	0.88	0.76
0.25	7.55	6.28	5.54	4.63	3.82	2.79	2.23	1.87	1.63	1.36	1.07	0.88	0.76
0.30	7.03	5.88	5.19	4.39	3.67	2.70	2.18	1.84	1.60	1.34	1.06	0.88	0.76
0.40	6.27	5.30	4.74	4.03	3.40	2.57	2.10	1.79	1.57	1.32	1.06	0.87	0.76
0.50	5.74	4.91	4.40	3.80	3.23	2.48	2.04	1.75	1.54	1.31	1.05	0.87	0.76
0.70	4.99	4.34	3.93	3.45	2.98	2.34	1.96	1.70	1.51	1.29	1.04	0.87	0.76
1.00	4.25	3.77	3.47	3.11	2.73	2.21	1.88	1.65	1.48	1.27	1.04	0.87	0.76
1.50	3.63	3.31	3.08	2.82	2.53	2.10	1.81	1.61	1.45	1.25	1.03	0.87	0.76
2.00	3.20	2.98	2.82	2.63	2.39	2.03	1.77	1.58	1.43	1.24	1.02	0.87	0.76

*Reactance expressed in per cent based on total kv-a. rating of synchronous machines. This includes both internal reactance of machines and reactance of external circuit reduced to the above basis.

†Rated full-load current based on maximum continuous kv-a. rating of synchronous machines. When the equivalent reactance of line, reactor, transformer, or combination of these expressed in per cent based on the total synchronous machine rating exceeds 150 per cent. The current to be interrupted may be determined directly from the reactance. This is due to the fact that under those conditions the generator reactance and the time of opening of the breaker may be neglected.

appreciably reduce the ratio between short-circuit and rated amperes. For example, assuming 10 per cent reactance and a short-circuit current containing the maximum possible direct component, the ratio of the peak value of the first alternation of the short circuit current to the peak value of rated current is roughly twenty. Under the same conditions the ratio of the r.m.s. value of the first alternation of the short circuit current to the r.m.s. value of the sinusoidal rated current is roughly seventeen.

The effect of using the flux at rated voltage and the assumed load instead of at rated voltage and no-load is to increase the short circuit current by a somewhat less percentage than the alternator reactance percentage. This effect in alternators of low reactance relatively is unimportant but assumes increasing importance as the alternator reactance increases.

The characteristic shapes of the time-current decrement curves have been arrived at by analysis of alternator tests including oscillograph studies of short circuits occurring when the alternators were excited to full voltage and were carrying various loads at various power factors.

In the curves for total reactances up to and including 20 per cent, the reactance is assumed to be wholly within the alternator and for higher values of reactance the alternators were taken at 20 per cent and due allowance made by calculation for the effect of the external reactance. In the latter case, if alternators of other reactance had been assumed the results would have been somewhat different but the error is not large enough to be of practical importance.

The final values of the current *i.e.*, the sustained short-circuit current, have been assumed in accordance with experience and tests and are based on the behavior of machines of normal design.

The study of representative oscillograms of short-circuit tests showed that in most cases the direct component disappeared within 0.5 second and that the transient portion of the alternating component disappeared within 3.0 seconds. These time values have therefore been used in constructing the characteristic curves.

Several alternators with the same reactance and synchronous impedance will not necessarily have the same rate of r.m.s. current decay. This has been considered in constructing the characteristic curves and they may safely be taken as representing the greatest r.m.s. currents that will be given by modern alternators of normal design.

These curves are applicable for selecting circuit breakers for systems as follows

1. Single machines without external reactance.
2. Single machines in combination with external reactance.
3. Multiple machines with no external reactances.
4. Multiple machines in combination with external reactance.

Examples

In order to illustrate the use of these curves in making oil circuit breaker selections, the following examples are given:

Example 1. (Arrangement of apparatus shown in Fig. 4.) Alternator rating 5000 kv-a., 2300 volts three-phase, 1250 amperes. Breaker contacts part in 0.25 second after start of short circuit. From table, under 12 per cent reactance, we find that at 0.25 second the current will be 5.54 times normal, therefore

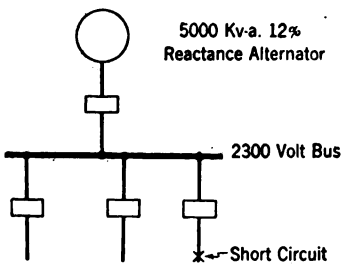

Fig. 4

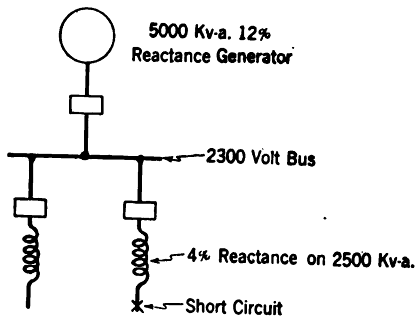

Fig. 5

the short-circuit current equals 5.54 × 1250 amperes = 6950 amperes.

Example 2. (Arrangement of apparatus shown in Fig. 5.) Alternator rating 5000 kv-a., 2300 volts, three-phase 1250 amperes. Feeder rating 2500 kv-a. Feeder reactance 4 per cent based on 2500 kv-a. Breaker contacts part in 0.25 second after start of short circuit.

Alternator reactance based on 5000 kv-a.	=	12 per cent
Feeder " " " " "	=	8 per cent
Total " " " " "	=	20 per cent

From the table under 20 per cent reactance, we find that at 0.25 second the current will be 3.82 times normal, therefore the short-circuit current equals 3.82 × 1250 amperes = 4780 amperes.

Example 3. (Arrangement of apparatus shown in Fig. 6.)

Alternator A rated 2000 kv-a., 2300 volt, three-phase reactance = 8 per cent

Alternator B rated 5000 kv-a., 2300 volt, three-phase reactance = 12 per cent

Alternator C rated 8000 kv-a., 2300 volt, three-phase reactance = 16 per cent

Total alternator kv-a., 15,000

Normal current based on 15,000 kv-a., 2300 volts = 3760 amperes.

Breaker contacts part in 0.4 second after start of short circuit.

Alternator	reactance	based on 15,000 kv-a.				= 60 per cent
"	B	"	"	"	"	= 36 per cent
"	C	"	"	"	"	= 30 per cent

Total reactance at bus = 1/60 + 1/36 + 1/30 = 12.9 per cent.

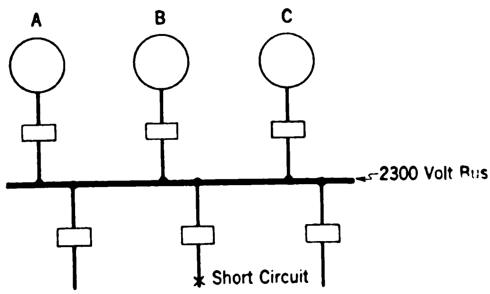

FIG. 6

From the table, interpolating between 12 per cent and 15 per cent reactance, we find that at 0.4 second the current will be 4.53 times normal; therefore, the short circuit current equals 4.53 × 3760 amperes = 17,030 amperes.

Example 4. (Arrangement of apparatus shown in Fig. 7.) Same as example 3, excepting that power is distributed over 2500 kv-a. Feeders in which are installed current limiting reactors having a reactance of 3 per cent based on 2500 kv-a.

Breaker contacts part in 0.4 second after start of short circuit.

Total alternator	reactance	based on 15,000 kv-a.				= 12.9 per cent
Feeder	"	"	"	"	"	= 18 per cent
Total	"	"	"	"	"	= 30.9 per cent

From the table using 30 per cent reactance, we find that at 0.4 second the current will be 2.57 times normal: therefore, the

short-circuit current equals 2.57 × 3760 amperes = 9650 amperes.

Example 5. (Arrangement of apparatus shown in Fig. 8.) Breaker contacts part in 0.1 second after start of short circuit.

Alternators same as for example 3.

Transformer banks each 7500 kv-a.; reactance = 6¼ per cent based on 7500 kv-a.

Lines: 20 miles of 1/0 copper; reactance = 5.5 per cent based on 7500 kv-a.

Total alternator reactance based on 15,000 kv-a. = 12.97 per cent.

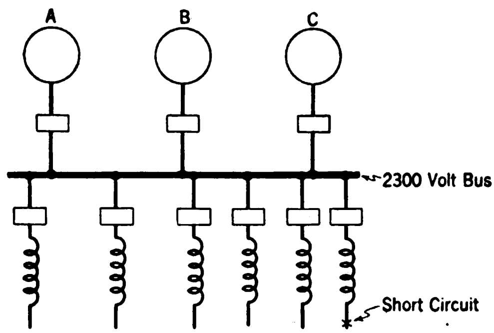

FIG. 7

Parallel reactance of step up transformers based on 15,000 kv-a.	=	6.25 per cent
" " " lines based on 15,000 kv-a.	=	5.5 per cent
" " " step down transformers based on 15,000 kv-a.	=	6.25 per cent
Total reactance....................	=	30.9 per cent

From the table, using 30 per cent reactance, we find that at 0.1 second the current will be 3.41 times normal. The normal current based on 15,000 kv-a., 11,000 volts, three-phase = 788 amperes; therefore, the short circuit current equals 3.41 × 788 amperes = 2690 amperes.

Example 6. (Arrangement of apparatus shown in Fig. 9.) Breaker contacts part in 0.4 second after start of short circuit. Conditions same as for example 5 except that a 475 kv-a., 2300-volt feeder has been added to the low voltage distribution.

Transformer reactance, 3 per cent based on 475 kv-a.
Total reactance up to 11,000-volt bus
based on 15,000 kv-a. = 30.9 per cent
Feeder transformer reactance
based on 15,000 kv-a. = 94.5 per cent

Total reactance based on 15,000 kv-a. = 125.4 per cent

From the table, using 125 per cent reactance, we find that at 0.4 second the current will be 0.87 times normal. The normal current based on 15,000 kv-a., three-phase 2300 volts = 3760

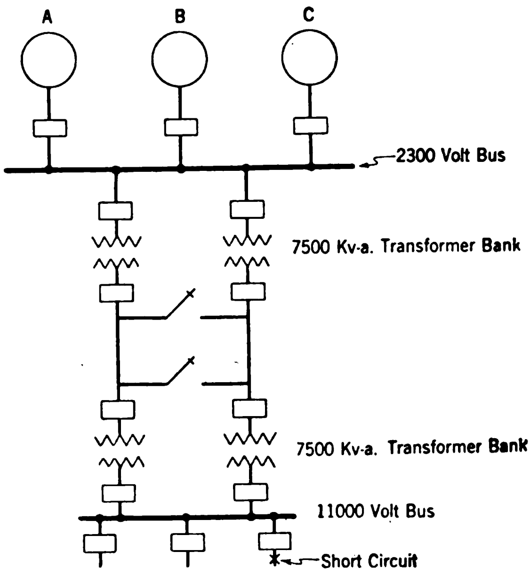

FIG. 8

amperes, therefore the short circuit current equals 0.87 × 3760 amperes = 3270 amperes.

With reactance of 125 per cent or higher values, the alternator portion of the total reactance becomes of small importance. In example 6 for instance, we have a total reactance of 125.4 per cent. The alternators in this example have a reactance of 12.9 per cent. If the reactance of the external circuit only is considered we have a total reactance of 125.4 per cent − 12.9 per cent = 112.5 per cent.

The short circuit current on this basis would be

$$\frac{100}{112.5} \times \text{normal, or } 0.890 \times 3760 = 3340 \text{ amperes.}$$

Comparing this value with the 3270 amperes obtained by considering the alternator reactance we have an error of approximately 2 per cent.

If the total reactance is greater than about 125 per cent or 150 per cent, the error will be even less than 2 per cent. For values of external reactance in excess of the table values the alternator reactance may be omitted.

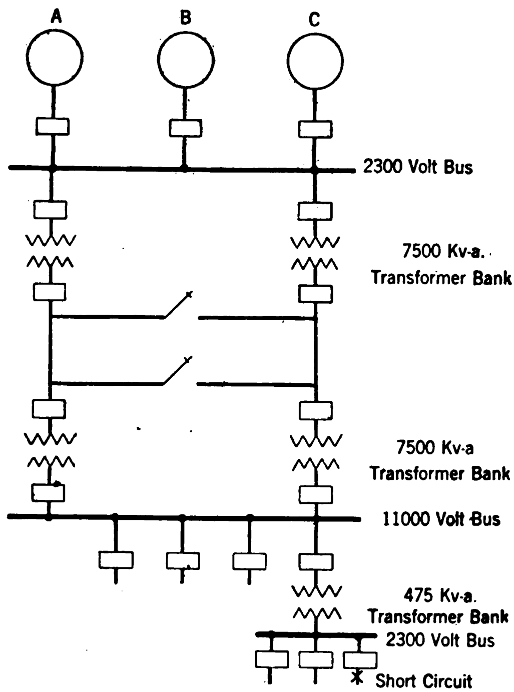

FIG. 9

PRECAUTIONS

The data given for the selection of oil circuit breakers is applicable only to average systems. Therefore, a short discussion of other factors requiring separate or more detailed attention seems worthy.

Automatic voltage regulators may introduce system transients differing from those which occur on systems not so equipped.

When the alternators are equipped with automatic voltage regulators such regulators will increase the excitation after a short circuit in the endeavor to hold normal voltage on the bus

bars. The maximum voltage which can be obtained from the exciters will ordinarily be not more than 50 per cent greater than that required at full load, 80 per cent power factor on the alternators. Under short circuit, the alternator terminal voltage is reduced, hence the resultant flux density in the alternator iron is also reduced. A given increase in excitation, therefore, produces a proportionate increase in current flowing in the short circuit. Hence, as we have assumed the excitation to increase 50 per cent, the sustained short circuit current will be approximately 50 per cent greater than the sustained current due to full-load 80 per cent power factor excitation.

An appreciable time, however, is required for the excitation to increase to its maximum value. During the first half second the amount of short circuit current is not affected by the presence of the voltage regulator, but from this time on the current curve is higher, reaching the value at the end of two to three seconds of 50 per cent greater than the current without the regulator.

An exception to the above appears when the external reactance is so high and the short circuit current so limited that the regulator is able to maintain normal voltage at the generator terminals. In such cases the sustained current may not be increased as much as 50 per cent, but will be limited to the current which will pass through the external reactance with normal voltage impressed upon it.

The interval between the occurrence of the short circuit and the parting of the circuit breaker contacts has, as study of the selection curves will show, an appreciable bearing on the oil circuit breaker that will be selected. The time values usually given for the operation of breakers assume that the breakers have been properly maintained and that their operation will not be impaired by factors resulting from neglect of maintenance or adjustment.

It is believed that the manufacturers of oil circuit breakers should publish information similar to that outlined in this paper to serve not only as a guide in the application of electrical protective devices but also to assist in bringing about a more uniform selection and a better understanding of the various expressions and methods used in connection with the rating of this class of equipment.

To be presented at the Sixth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 15, 1918.

(*Subject to final revision for the Transactions.*)

A THERMOELECTRIC STANDARD CELL

BY C. A. HOXIE

ABSTRACT OF PAPER

This paper considers a means of obtaining a secondary standard of e. m. f. by utilizing the e. m. f. of a thermocouple. The standard thermo cell is fundamentally a standard of current, in that it requires a definite value of current to function properly.

The operation of the cell consists in balancing the potential across a resistance against the thermoelectric e. m. f. of the thermocouple. This requires a definite value of current through a filament which is a source of heat for the thermocouple.

The temperature coefficient has different values, depending upon the temperature of the heating filament. Means are provided for compensating for the temperature coefficient of the cell. The construction of the cell is discussed in detail, particularly the use of gas in the bulb.

A review of the characteristics brings out several advantages of the thermoelectric standard cell. The results of permanency tests on a number of cells are shown. The standard cell has been successfully applied to potentiometers designed for thermocouple work. Further experimental work on this cell is now under way.

MOST engineers are familiar with the uses and limitations of standard cells of the Clark or Weston types. Those who have used either of these cells know that they will not function at freezing or boiling point temperatures, and are easily damaged if an appreciable current is drawn, as by accidental short circuiting.

Though the "Thermal" cell about to be described is not, strictly speaking, a primary standard or source of e. m. f., as is the Clark or Weston cell, it is at least free from the above drawbacks. It may be more properly classed as a secondary standard, its value being determined by comparison with a primary standard. In fact it is just as legitimate to call it a standard of current as of e. m. f., and perhaps a little more so, for the reason that it is simply a combination comprising a resistance, a thermo junction and a heater wire arranged in such a manner that it requires a current of a certain definite value in order for it to function properly. A standard value of e. m. f., however, may

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be obtained by taking the drop across a suitable resistance placed in the circuit.

To be more explicit, the standard thermal cell in its present form consists of a glass bulb containing a thermo junction T, (see Fig. 1) a heating filament H which is not in contact with the junction, the balancing resistance R and the drop resistance R_1. These are mounted in a case with binding post connections on the top. (See Fig. 2.)

OPERATION

If a battery and galvanometer are connected as shown in Fig. 1, and the current adjusted to a critical value the galvanometer will indicate a balance. The reason for this may be readily understood by reference to Fig. 3. The curve a represents the

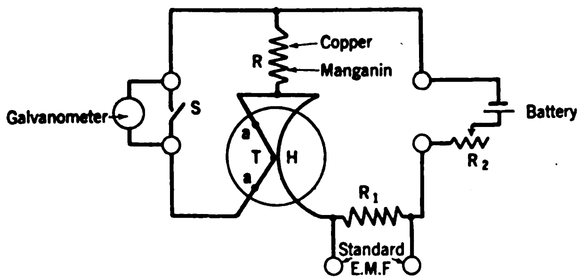

FIG. 1—DIAGRAM OF STANDARD THERMO-CELL CIRCUIT

T = Thermo junction
H = Heating filament
a = cold end
R = Balancing resistance
R_1 = Drop resistance
R. = Rheostat
s = Galvanometer short-circuiting switch

drop of potential across the balancing resistance R as a function of the current through the heater H. The curve b shows variation of the thermal e. m. f. of the junction with the current through the heating filament. These curves indicate that the thermal e. m. f. is approximately proportional to the second power of the current through the heater, while the drop across the resistance R varies directly. The point of intersection C of these curves is that point at which the thermal e. m. f. equals the drop of potential across the balancing resistance. Therefore by adjusting the current through the heating filament to this critical value, we have a means of obtaining a definite potential drop across the resistance R_1. In order to obtain a high value of thermal e. m. f. it is desirable to heat the filament to a high

temperature. The maximum current that can be used without effecting the constancy of the cell, is that which will bring the filament to a dull red heat when viewed in a dark room. Under actual operating conditions the filament current is generally maintained somewhat below this value to prevent damaging the cell due to an accidental increase.

In many of the tests with these cells a lead storage battery having a maximum variation in e. m. f. from 2.4 to 0.8 volts has been employed. By reducing the filament current to about 10 per cent below the reddening point, the cell can be constructed so that 2.4 volts applied to its terminals will not damage the cell. The adjustment to the critical balancing current is then secured by means of a rheostat in the battery circuit.

Temperature Coefficient. Since the drop and balancing re-

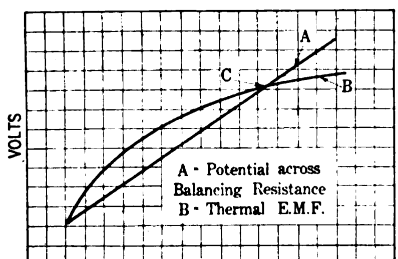

FIG. 3—CURVES SHOWING RELATION BETWEEN POTENTIAL DROP ACROSS BALANCING RESISTANCE AND THE E. M. F. GENERATED AT THE THERMO JUNCTION

sistances are constructed of wire which has a negligible temperature coefficient, any change in the potential across the drop resistance must be due to a variation of the thermal e. m. f.

It is found that when the cell has been adjusted so that the current necessary for a balance is sufficient to bring the filament to a dull red heat, the cell has no measurable temperature coefficient. If adjusted to any smaller value of current a negative coefficient results. This is due to the fact that up to a certain point, a rise in the surrounding temperature increases the thermal e. m. f. of the couple for a given difference in temperature between the cold and hot ends. Apparently this critical point is reached when the filament attains a dull red heat.

The fundamental cause of the temperature coefficient of the cell is, as previously stated, the positive temperature coefficient of the thermal e. m. f. If a portion of the balancing resistance

is constructed with the proper amount of some metal having a positive temperature coefficient, the increase in thermal e. m. f. is balanced by an increased drop across the balancing resistance, hence it becomes unnecessary to vary the filament current. We have therefore compensated for the temperature coefficient of the cell.

Construction

Considerable experimental work was necessary to determine the proper construction of the various parts of the thermal cell. The results of this work will now be discussed.

Heating Filament and Couple Wires. The heating filament and junction wires are kept under tension in order to maintain a constant position with respect to each other. The tension is produced by small spirals located at the base of the bulb. Even with this construction, it is probable that the relation between the heater and the filament will vary, due to contraction and expansion of the metal springs.

At first we would say that any variation in this separation would seriously effect the thermal e. m. f. Experiments show that small differences of separation did not effect the e. m. f. generated at the junction. The explanation of this phenomena is found by considering the transfer of heat from small wires in gases.* It has been found that loss of heat from wires by free convection takes place as if a gaseous film surrounded the wire and the heat was transferred through this film by conduction. It has also been determined that the thickness of the film is independent of the temperature but is dependent upon the diameter of the wire. Evidently if we assume other factors constant, we will obtain a steady transfer of heat from the heating filament to the junction, if we arrange the junction so that it always remains within the gaseous envelope surrounding the heater.

The characteristics of both junction and heater wire must be carefully considered. The heater wire should be of small diameter and of a material having a high resistance and capable of withstanding considerable strain when heated to a cherry red. Tungsten wire 0.07 mm. in diameter was found to meet these requirements and gave the proper temperature with a current of about 40 milliamperes. Experiments indicate that cells constructed with a heater wire of larger diameter do not remain

*"Connection and Conduction of Heat in Gases" by Irving Langmuir, *Physical Review*, 6-12, vol 34, p. 408.

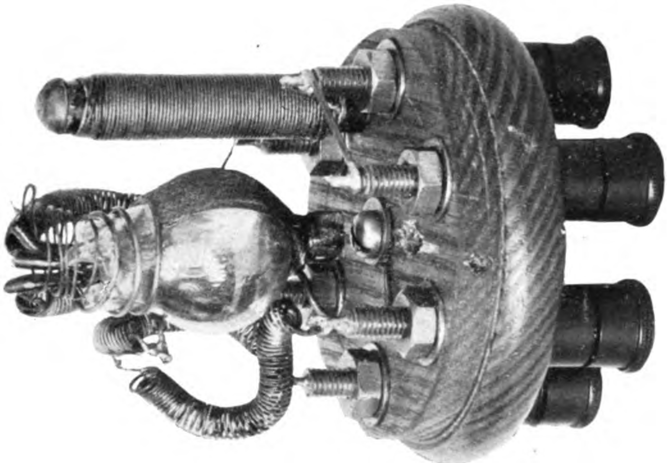

FIG. 4 [HOXIE]

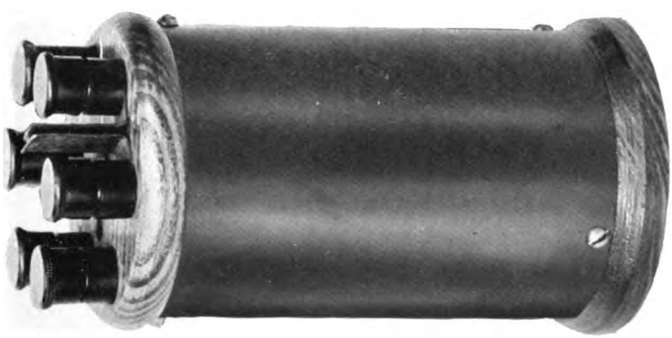

FIG. 2 [HOXIE]

constant. A heating filament of about 1 cm. in length and having a resistance of approximately 12 ohms has given good results.

The couple wires should have as small diameter as possible in order to decrease the conduction of heat, reduce the lag to a minimum and to permit reaching a maximum temperature. The couple and heater wire are mounted on a single glass stem and after an adjustment of their relative positions has been made, this working unit is placed in the glass bulb.

Use of Gas in Bulb. If we produce a high degree of exhaustion in the bulb a low thermal e. m. f. must result. Conversely, if this bulb is filled with gas under pressure, the junction will develop a high thermal e. m. f. the temperature of the filament being the same in both cases. In the first case the transfer of heat by convection is practically eliminated, leaving only the loss of heat by radiation from the small heater wire. This is negligibly small up to a temperature of several hundred degrees. In the second case, the heat is transferred so rapidly by convection that a high current value is required for the heater. Besides affecting the thermal e. m. f., the amount of gas is an important factor in the operation of the cell. Experiments have shown that if the amount of gas exceeds a certain value the cell becomes very sensitive to even slight changes in position. The thermal e. m. f. increases as the junction approaches the point directly above the heating filament.

Nitrogen gas under a pressure of about 2 cm. has given good results. It permits the operation of the cell in any position and a transfer of heat sufficient to produce the required e. m. f. In the construction of the cell, the bulb is first exhausted to about 0.4 microhms. It is then heated to approximately 350 deg. cent. to eliminate moisture, at which time the gas is admitted and the bulb sealed off. A second filament, heated to high temperature for a few minutes is used to eliminate the impurities in the gas.

Aging of Filament. After the bulb has been assembled, the current is passed through the filament, raising its temperature to a point considerably beyond the final operating value. This ages the filament and increases the permanency of the cell. (Experiments were made to determine if it were possible to age the heating filament wire before placing in the bulb. This did not seem to produce the desired aging effect, even when heating the filament to a high temperature in gas. Possibly the wire

was aged, but the handling necessary to assemble it in the bulb, may have resulted in mechanical strains sufficient to nullify the aging.) Tests are then made to determine the proper values of R and R_1, also the amount of positive temperature coefficient metal to be inserted in the balancing resistance.

Connections Bewteen Bulb and Binding Posts. Any lag in the temperature of the balancing coil with respect to that of the heater and the couple wires is prevented by spiralled connections, as shown in Fig. 4. By spiralling the connections from the bulb to the binding posts on the top of the cell the heat conducting path is lengthened, so that changes in the surrounding temperature have a uniform effect on all parts of the cell.

Characteristics

The e. m. f. obtainable from this cell is not limited as in other types. The drop resistance may be adjusted so that the potential across it can have any desired value, usually one volt. Any combination of e. m. f. values however, may be obtained by taking taps from the drop resistance.

Temperature Coefficient. As previously shown the temperature coefficient may be reduced to zero.

Effect of Temperature. The surrounding temperature may vary from values below 0 deg. cent. to over 100 deg. cent. without the slightest injury to the cell. This is due to the fact that no liquid is used in its construction.

Effect of Short Circuit on Cell. When these cells are properly constructed they cannot be damaged by short-circuiting any of the external connections.

Accidental Increase of Filament Current. An excessive current through the filament may change the standard value of e. m. f. but will not necessarily destroy the usefulness of the cell. This effect will be considered under "Results of Tests."

Position of Cell. The position of the cell does not affect the value of the standard e. m. f.

Strength. The cells are readily portable and will stand severe shocks without injury. They can be easily shipped if ordinary precautions are taken in packing.

Accuracy. Due to the fact that a null method is employed in balancing the cell, the observation error will be a minimum one. The principle sources of error are the temperature coefficient of the cell and thermal e. m. f's. other than the e. m. f. generated at the junction. The error due to thermo e. m. f's. in

the galvanometer circuit may be reduced to a minimum by short-circuiting the galvanometer circuit* at the standard cell. The galvanometer will then indicate the true zero which must be used in obtaining the balance of the cell. Furthermore, any error in the thermo junction circuit introduces but half the per cent error in the potential measured across the drop resistance. As previously stated this is due to the fact that the thermal e. m. f. of the junction circuit is proportional to the square of the current through the filament, whereas the potential across the drop resistance is directly proportional to this current. A standard thermo cell that is properly constructed and operated should remain constant to at least 5 parts in 10,000. It is probable that in view of experiments now under way that the constancy of these cells will be greatly improved.

Permanency Tests. In Fig. 5 is shown the results of tests on standard thermo cells 1 to 8 inclusive. These tests cover a period of 14 to 23 months and are representative of a considerable number of cells. The following table gives the results of these tests:

Cell No.	Original e. m. f.	Maximum variation. Parts in 10,000	Avg. variation from orig. e. m. f. Parts in 10,000	No. of tests	Period covered by tests. Months
1	0.9890	2.0	0.0	27	23
2	1.0199	5.0	1.4	21	14
3	1.1294	3.0	1.0	16	15
4	1.0645	4.0	1.1	20	16
5	1.2004	4.0	1.4	14	14
*6	1.0376	3.0	0.2	5	4
†6	1.0371	4.0	0.4	14	11
7	1.1833	6.0	2.1	14	12
*8	0.9828	5.0	2.0	17	15
†8	0.9791	4.0	1.6	9	7

*Before filament temperature was accidently increased to reddening point.
†After filament has been brought up to reddening point.

Results of Tests. The curves for cells 6 and 8 indicate the effect of increasing the filament temperature above the reddening point. As previously stated, this produces a permanent increase in the filament resistance. It follows that when the filament resistance is increased, the heater current must be decreased to obtain the new balancing point *C*. See Fig. 3. This decrease

in current of course results in a smaller potential across the drop resistance. It is interesting to note, that after the heating filament resistance has changed, the cell continues to function properly except that a lower value of e. m. f. is obtained, assuming of course, that the drop resistance is not changed. In the event of an accident of this nature the standard e. m. f. may be restored to its original value by adjusting the drop resistance.

Conclusion

In conclusion, it is believed that the characteristics of the standard thermo cell justify its use in many measurements in which standard cells are now required. This cell has been successfully used with potentiometers designed for thermocouple

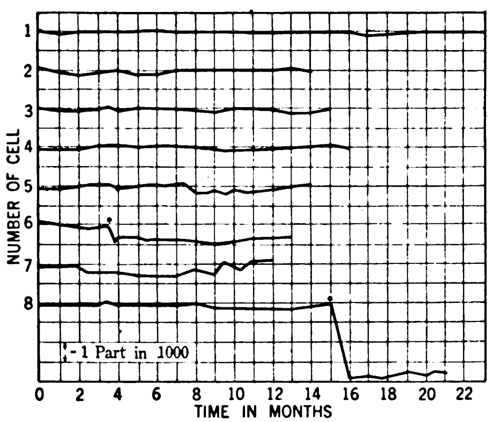

Fig. 5—Curves Showing Constancy of Typical Standard Thermo Cells

*Filament current accidentally overheated at this point

work. During the past year several of these potentiometers have been in constant use, and were operated by unskilled labor. During this period no trouble has been experienced that could be charged to the standard cell. Several cells have been burned out through the carelessness of the operator. In every case of a damaged cell it has been found that either the galvanometer or the slide wire or both were destroyed.

Very little experimental work has been done during the past year due to conditions imposed by the war. There is still considerable work to be done on the cell some of which is now under way.

To be presented at the Sixth Midwinter Convention of the American Institute of Electrical Engineers, New York, N. Y., February 16, 1918.

THE SECOMOR

A KINEMATIC DEVICE WHICH IMITATES THE PERFORMANCE OF A SERIES-WOUND POLYPHASE COMMUTATOR MOTOR

BY V. KARAPETOFF

ABSTRACT OF PAPER

The device consists of four bars of adjustable useful length and with adjustable angles. These bars can be set in a combination to represent the vector diagram of voltages in a motor with any desired constants. By moving the bars to vary the load, complete performance characteristics of the motor can be obtained, including the speed, the torque, the power factor, etc. An additional device called the impedometer permits to take into account the impedance drop in the machine. An adjustable saturation curve made of soft wire is used in connection with the secomor, to enable one to investigate the effect of saturation. A brief graphical theory of the motor precedes the description of the secomor to make its action understandable.

A. INTRODUCTION

THE MEANING of the Name Secomor: An abbreviation of the words "series commutator motor".

What the Secomor is. A combination of movable and adjustable bars (Fig. 9) which can be set to represent a vector diagram of voltages, currents, m.m.f's and fluxes in a series-wound polyphase commutator motor with any desired constants.

The Purposes of the Device. (1) To enable a designer to select the best electrical constants and to "test" a motor before it has been actually built; (2) To take the place of a complicated circle diagram which does not hold true anyway when the iron is saturated; (3) To do away with an involved analytical theory because it is often difficult to see the effect of separate factors upon the performance characteristics, and because it takes considerable mathematical skill to deduce the equations of the various loci; (4) To add the judgment of the eye and the skill of the hands to the purely mental ability in selecting the constants of a motor for a desired performance, or in judging the

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characteristics for assumed constants; (5) To enable an investigator or a student to familiarize himself with the motor as if he had one available for tests.

The performance curves that the secomor enables one to draw: Current, torque, speed, input, output, efficiency, power factor, magnetizing current. These may be obtained just as easily at a constant applied voltage as at a constant current, or under any variable conditions of service.

The factors which may be taken into account and varied at will in the secomor: The ratio of the primary to the secondary ampere turns; the ratio of either one to the exciting m.m.f.; the angle of brush shift; the ohmic drop and the reactive drop; saturation in iron; variable core-loss and friction; reaction of short-circuited armature coils upon the exciting current.

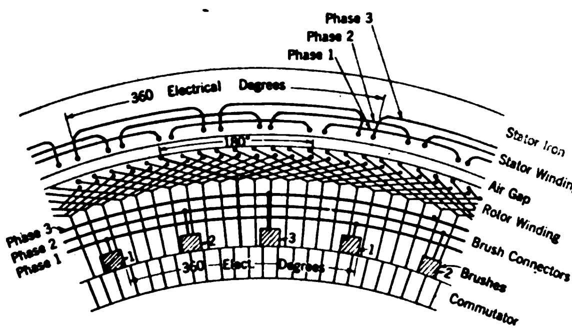

FIG. 1

B. General Properties of the Motor

A detailed description of the motor, its field of application, its performance characteristics and a complete theory, both graphical and analytical, will be found in E. Arnold's "Die Wechselstromtechnik", (1912) Vol. V, Part 2, Chap. 2. See also the bibliography below.

Diagrams of connections are shown in Figs. 1, 2 and 3. The stator is phase-wound and is similar to that of an induction motor. The rotor is like a d-c. armature with a commutator. With a multiple armature winding the number of brushes per pair of poles is equal to the number of phases; with a two-circuit winding it is considerably less.

The rotor is connected in series with the stator, either directly (Fig. 2), or through a current transformer (Fig. 3). In the latter case the stator may be either star or mesh connected.

Characteristics and the field of application. The motor has a speed-torque characteristic similar to that of a d-c. or single-phase series motor. As the load increases the speed decreases. At no-load there is a tendency to run away. Roughly speaking, one may consider the motor as a combination of three single-phase series-connected motors built on the same frame. On account of the mutual action between the phases such a view is

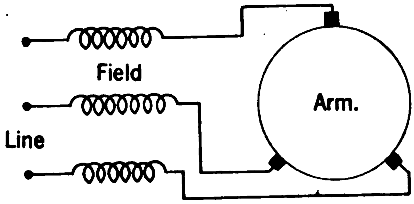

FIG. 2

not quantitatively correct. The motor may be used for crane service and in other applications in which it may replace a series-wound d-c. motor. A peculiar field of its own is in cascade connection with an induction motor, as a counter e.m.f. arrangement for speed control. This is useful in mine-hoist work and in rolling mills; see Arnold, p. 266. A shunt-connected polyphase commutator motor is also suitable for cascade connection.*

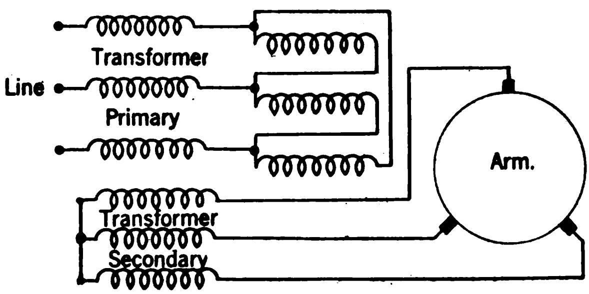

FIG. 3

Advantages of a series transformer (Fig. 3): (a) The stator may be wound for a comparatively high voltage, *e.g.*, 2200 volts; (b) The rotor may be wound for such a value of current as to give the best commutation; (c) When the machine is used as a generator, for example in regenerative braking, there is a possibility of a harmful direct current or of low-frequency alter-

*See J. D. Wright, *General Electric Review*, 1916, p. 104.

nating currents produced in the armature, due to self-excitation. By saturating the current transformer this tendency is counteracted; see Arnold, p. 64. (d) By properly selecting the saturation and the magnetizing current of the transformer the speed above synchronism may be controlled to some extent, so that the motor does not run away when the load is removed.

Four fundamental properties of an armature connected to a polyphase a-c. circuit through a commutator and brushes, Figs. 1 *and* 2.

(a) The *currents* in the armature conductors are of the same frequency as the line currents, independent of the speed of rotation. Call the armature coils (Fig. 1) between two adjacent brushes "a group". The function of the commutator is to transfer the coils in succession from one group to the next. But a new coil is always substituted in place of the one transferred, so that *the group persists* and forms a steady path for the line currents. This, of course, does not apply to the coils undergoing commutation, in which high-frequency currents are induced.

(b) The *voltages* induced in the armature conductors are always of the same frequency as that of the stator flux which induces them. The relative speed of rotation of the flux and armature influences only the magnitude of the induced voltage but not its frequency. Consider a d-c. machine in which the field current and the flux are periodically varied. The e.m.f. induced between the brushes undergoes corresponding fluctuations. If the field be varied harmonically, the induced e.m.f. will also vary at the same frequency according to a sine law. Speeding up the armature or slowing it down will influence the value of the induced voltage, but its frequency is always that of the flux. With a constant flux the voltage is also constant. Similarly, in an a-c. motor the instantaneous voltage induced in a group of coils between adjacent brushes is proportional to the instantaneous value of the stator flux and to the speed of rotation. The stator flux varies at the impressed frequency, and so does the induced voltage. This simple property of armature currents and voltages makes it possible to use vector diagrams at any speed of rotation. It will be remembered that in an induction motor (without commutator) the frequency of the secondary currents depends upon the speed of the rotor.

(c) The *magnetomotive force* and the *flux* due to the armature

currents are nearly the same whether the armature is revolving or is at rest, provided that the armature current is kept constant. We have seen above that the groups of armature coils between the brushes are always stationary, and the currents that flow through these groups are of the same frequency as the line currents. Hence, the *m.m.fs. of the individual groups* are stationary in space at all speeds of the armature. The combined action of several groups of coils produces a revolving field, same as in the stator winding, and this field glides synchronously in the air-gap with respect to the brushes, no matter what the speed of the armature might be. The m.m.f. due to high-frequency currents in the coils undergoing commutation is a disturbing factor, being a function of speed, current, stator flux, etc., but its effect is usually small. For its computation see Arnold, pp. 23 and 56.

(d) The *leakage reactance* of a commutated armature is a function of its speed, unlike that of ordinary a-c. windings. Two kinds of leakage fluxes may be distinguished, (1) those linking with individual armature conductors or with groups of conductors belonging to the same phase, and (2) those linking with conductors belonging to different phases. The first named fluxes (phase leakage) are carried around with the conductors and cause a reactance drop which is independent of the speed of rotation of the armature. The latter fluxes (interlinked leakage) in combination form a true revolving flux which glides synchronously in the air gap whether the armature is standing still or revolving at any speed.

The effect of the interlinked leakage flux depends upon the slip of the armature. At synchronous speed the armature conductors do not cut this flux at all, and the only reactance is that due to the phase fluxes which travel with the conductors. At standstill the interlinked leakage flux exerts its full effect. As speeds above synchronism the armature conductors cut this flux in the opposite direction, so that it partly compensates for the effect of local or phase fluxes. At a certain synchronous speed the total armature reactance becomes zero, and beyond that speed it becomes negative. Whatever the theory of the phenomenon, actual experiments show that the reactance of a commutated armature winding decreases with increasing speed. See Arnold, p. 20.

Brush shift and the m.m.fs. The alternating currents in the three stator phases together produce an m.m.f. M_1 (Fig. 4) of

constant amplitude. This m.m.f. is distributed in space approximately according to a sine law, and it glides synchronously along the air gap. The action is the same as in the stator of an ordinary polyphase induction motor; see for example the theory

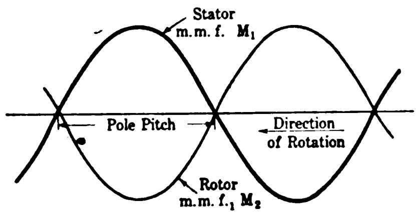

Fig. 4

as treated in the author's "Magnetic Circuit", p. 128. The three rotor currents together produce a similar gliding magnetomotive force M_2, whether the armature is revolving or stationary. Its position in space with respect to M_1 depends only upon the

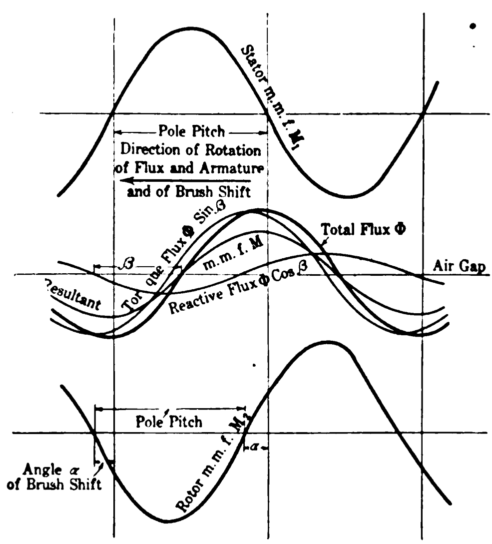

Fig. 5

angle of brush shift and is independent of the value of the current or of the speed of rotation. This is because the m.m.fs. in a commutated armature are the same as if the armature were at rest (see proof above). In a certain position of the brushes called *neutral* the stator and the rotor m.m.fs. are in phase

opposition in space (Fig. 4). In this paper the angle of brush shift α is measured from this position. Arnold measures the brush shift angle ρ from the position at which M_1 and M_2 are in phase coincidence. Hence, his ρ = 180 deg. $-\ \alpha$. In the secomor it is more convenient to deal with an acute angle α than with an obtuse angle ρ.

The Torque. In the neutral position of the brushes (Fig. 4) the mechanical force between the stator and the rotor is simply a radial repulsion, and the motor develops no torque. Let now the brushes be shifted by an angle α (Fig. 5) in the direction of rotation of both m.m.fs. The resultant m.m.f. M in the air-gap is equal to the sum of M_1 and M_2, and the flux Φ which M produces is out of phase with M_1 and M_2. The relations shown in Fig. 5 are also indicated vectorially in Fig. 6, which is a *space* (not time) diagram. The actual air-gap flux Φ may be resolved

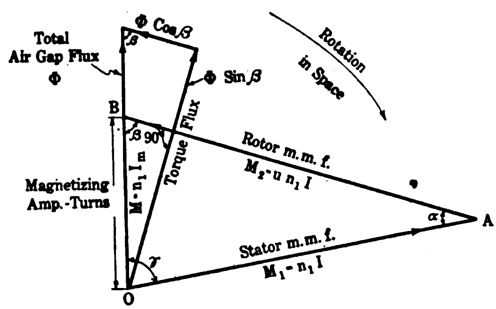

FIG. 6

into two space components, one in phase (or phase opposition) with M_2, the other in quadrature with it. These components are marked $\Phi\ \cos\beta$ and $\Phi\ \sin\beta$ respectively. The in-phase component $\Phi\ \cos\beta$ increases or reduces the fictitious flux due to the rotor winding itself, and produces no torque with the armature currents. The useful torque is due entirely to the interaction between the quadrature component $\Phi\ \sin\beta$ of the air-gap flux and the armature m.m.f. M_2. There is a similar relationship in a d-c. machine with the brushes in the neutral, no torque being produced between the armature conductors and the flux of armature reaction. The useful flux must be in space quadrature with that which the armature windings themselves excite.

Direction of Rotation of the Armature. By marking the directions of the currents and fluxes in Fig. 5 and applying the famil-

iar right-hand screw rule one finds that the torque is exerted upon the armature conductors in the direction in which the brushes are shifted from the neutral. A simple way to check this fact is to consider the fictitious fluxes due to M_1 and M_2 acting alone. Since the m.m.fs. are nearly in phase opposition, these fluxes repel each other, and the armature tends to carry ts m.m.f. away from M_1, by moving to the left. The stationary brushes fix definite groups of armature conductors in space, so that the armature moves away steadily without coming into a position of stable equilibrium. If the brushes were shifted in the opposite direction, the direction of rotation would be reversed. It is of importance to note that the characteristics

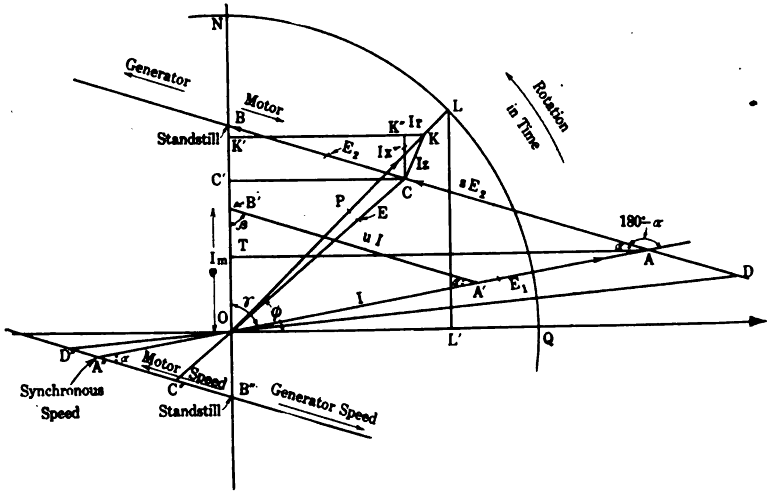

FIG. 7

of the motor are entirely different for the two directions of rotation. In the first case the armature conductors revolve in the direction of the flux, so that the rotor e.m.f. at synchronism becomes zero, and then its sign is reversed. In the second case the rotor e.m.f. increases indefinitely with the speed of rotation. In practise the first combination has been used so far, and is the only one considered in this paper.

C. Time Diagram of E.M.Fs.

Consider the motor running at a given current, which is kept constant and let the speed vary, the terminal voltage being adjusted for each speed. The e.m.fs. M_1 and M_2 are constant and

so is the resultant flux Φ, so that Fig. 6 applies at all speeds. The flux Φ induces certain e.m.fs. in the stator and rotor windings, and these e.m.fs. are shown in Fig. 7.

Fig. 7 is a time diagram, and it shows the applied voltage $O K = P$ consumed, in three parts: (1) $O A = E_1$ is that part of the applied terminal voltage which is equal and opposite to the e.m.f. induced by flux Φ in the stator windings. For the sake of brevity E_1 is further referred to as the stator voltage. (2) $A C = s E_2$ is the voltage consumed in the rotor, in opposition to the e.m.f. induced by flux Φ. (3) $C K = I_z$ is the impedance drop in the windings of the machine and in the brushes.

The voltage induced in the rotor is proportional to per cent slip, being zero at synchronism. Let $A B = E_2$ be the voltage which balances that induced in the rotor at standstill. With the brushes in the neutral, E_2 leads E_1 in time by 180 deg. Shifting the brushes forward by an angle α is equivalent to retarding the armature with respect to the revolving flux by the same angle, so that E_2 leads E_1 by (180 deg. $- \alpha$). At a slip s, the secondary voltage is no more $A B$, but is $A C = s E_2$. The resultant voltage $E = O C$ balances the total counter-e.m.f. of the machine.

In an ideal motor, without internal resistance or reactance, $O C$ is identical with the terminal voltage P. As the speed increases from zero to synchronism, with the current kept constant, point C moves along $B A$ from B to A. Above synchronism the sign of E_2 is reversed and point C moves further towards D. For points to the left to B the machine acts as a generator.

In an ideal motor no power is consumed at standstill so that the applied voltage $O B$ at the speed zero must be in leading quadrature with the horizontal current vector I, which is the reference vector. Thus $O B$ in the diagram must be vertical. As the speed increases the phase angle between $O C$ and I decreases. By continuing $B D$ further to the right to its intersection with I, a super-synchronous speed is found at which the applied voltage is in phase with the current. Beyond that speed, the motor takes in a leading current.

The Triangles of Voltages and of m.m.fs. are Similar. In the construction of the secomor use is made of the fact that the triangles $O A B$ in Figs. 6 and 7 are similar. The two m.m.fs., M_1 and M_2, being produced by the same current are displaced *in space* by 180 deg.$-\alpha$, where α is the brush shift angle measured from the opposition point (Fig. 5). Similarly, the two voltages,

E_1 and E_2, being induced by the same flux Φ, are displaced ***in time*** by 180 deg.$-\alpha$. The ratio of M_1 to M_2 is equal to that of the effective numbers of turns in the stator and in the rotor; the ratio of E_1 to E_2 is equal to the same ratio of turns. Thus, the two triangles have an equal angle between two proportional sides, and therefore are similar. This important relationship permits to incorporate the m.m.f. triangle $OA'B'$ in the time diagram (Fig. 7) and to do away with a separate space diagram. To take into account the m.m.f. of the short-circuited coils undergoing commutation a slight correction is necessary; see Arnold, p. 56.

Leakage Inductance. Both the stator and the rotor windings are linked with leakage fluxes, and the corresponding reactances cause a voltage drop in time quadrature with the current. The effect of the reactance is shown in Fig. 7 in the usual way, by adding a vector Ix to the voltage OC. As is explained above, the total armature reactance depends upon the speed of the machine, so that the vector Ix consists of two parts, one proportional to I only, and the other proportional to I and to the slip s.

Ohmic Drop, Iron Loss and Friction. The ohmic drop in the machine is taken into account in the usual way by means of the vector Ir in phase with I. In a variable-speed machine the iron loss is rather a complicated function of both the current and the speed, so that it is hardly feasible to take it into account in a vector diagram. The same is true to some extent of the friction and windage loss. The simplest way is to disregard them in the vector diagram and to correct the obtained values of input and output afterwards. One may also increase the actual ohmic resistance of the machine so as to include the iron loss in the term I^2r, and consequently in the vector Ir, but the procedure is of doubtful accuracy and value.

The Saturation Curve. In a series-wound machine it is hardly permissible to disregard the effect of saturation in the magnetic circuit upon the performance at large values of current. The starting torque and the characteristics at low speeds are appreciably affected thereby. Let Fig. 8 represent the a-c. saturation curve of the magnetic circuit of the machine. To obtain it experimentally, the brushes are raised from the commutator, and the armature is run at the synchronous speed by some external power. The stator winding is connected to a source of variable a-c. voltage, and a series of readings is taken of the

voltage E_1 and of the corresponding magnetizing current I_m. The values of E_1 are corrected for the ohmic drop and those of I_m for the core loss. The corrected values give the curve shown in Fig. 8. This curve is used in connection with the diagram in Fig. 7, and also in connection with the secomor.

D. Performance Characteristics of the Motor

The brush shift angle α and the ratio $u = M_2/M_1$ of the effective rotor turns to the effective stator turns are the data to begin with. These determine the shape of the triangle $O A B$ (Fig. 7). Its position with respect to I is also determined since $O B$ is perpendicular to I. Let $O A'B'$ be the m.m.f. triangle transferred from Fig. 6. Then if we make $O A'$ equal to I (in magnitude only, but not in phase), $O B'$ will represent the magnetizing current I_m. This is because in Fig. 6 all the three

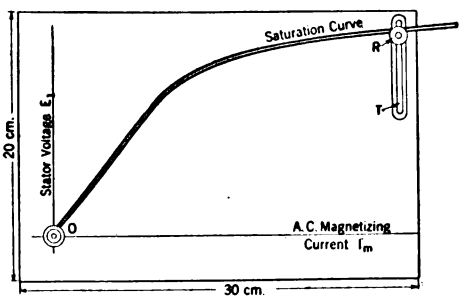

Fig. 8

sides of triangle $O A B$ have a common factor n_1, that is, the number of stator turns.

From the saturation curve (Fig. 8) we get the value of E_1 corresponding to this magnetizing current and lay it off as $O A$. This determines the direction $B D$. The rest of the problem is to find such a point C that the impedance triangle $I x$, $I r$, constructed at it, would give the desired terminal voltage $O K = P$ in magnitude. This is purely a geometrical problem which can be solved either analytically or graphically. In the secomor the point C is found mechanically, by means of a few simple trials, shifting one part of the device relatively to another. Herein lies one of the principal advantages of the secomor over the analytical or the graphical method.

Speed. In Fig. 7, $B C = (1 - s)\ E_2$, so that the speed of the machine $(1 - s) = B C/B A$, expressed as a fraction of the

synchronous speed. Instead of measuring every time two lengths and taking their ratio, it is convenient to draw an arbitrary straight line $A''B''$ parallel to $A\,B$. Produce $B\,O$ and $A\,O$ so as to get points B'' and A'', and divide $A''B''$ into 100 equal parts, beginning with zero at B''. Extend the divisions both ways to cover the operation above the synchronous speed, and also with the machine running backward as a generator. For any operating point, such as C, extend $O\,C$, and read per cent speed at C''. A proof for this construction follows directly from the similar triangles $O\,A\,B$ and $O\,A''\,B''$.

Input, Output and Efficiency. The vector $K\,K'$ is the component of the applied voltage P in phase with the current. Therefore $K\,K' \cdot I$ represents the input into the motor per phase. To it should be added the estimated core loss in the stator. The mechanical output is proportional to the component of the counter-e.m.f., E, in phase with the current; hence the output is equal to $C\,C' \cdot I$. The friction loss and the core loss in the armature should be subtracted from this value. The efficiency is found as the ratio of the true output to the true input.

Power Factor. The power factor, $\cos \phi$, is equal to the ratio of $K\,K'$ to $O\,K$. A simple way to read it directly is to draw the quadrant $N\,L\,Q$ with O as a center, using 100 convenient divisions, for example 100 mm., as the radius. The intersection L of $O\,K$ with the quadrant determines point L'. Radius $O\,Q$ is marked with a uniform scale, zero being at O to 100 at Q. Thus, the power factor is read at L' directly in per cent.

Torque. In a d-c. series-wound motor the torque is a function of the current and is practically independent of the speed. In the motor under consideration the torque is also independent of the speed, except for the disturbing effect of the armature coils undergoing commutation. The torque depends essentially upon the current and upon the brush shift. With the given I and α the torque is nearly the same at standstill as at any other speed. But at standstill $A\,T$ represents the energy component of both the stator voltage E_1 and the rotor voltage E_2. The amount of power $A\,T \cdot I$ is absorbed in the stator and an identical amount is returned to the line from the rotor. Thus, $A\,T \cdot I$ is the torque in synchronous watts, corresponding to I at any speed.

Another proof is as follows: In Arnold, on bottom of p. 41 the torque in synchronous watts is expressed as $I^2\,x_a\,u \sin \alpha$. Here $x_a = E_1/I_m$ is the so-called exciting reactance of the machine. Multiplying and dividing the foregoing expression

by I_m we get, torque $= I^2 x_a u \sin\alpha = E_1 I (u I \sin\alpha/I_m)$. But from the triangle $O A'B'$ (Fig. 7) we have that $u I/\sin\gamma = I_m/\sin\alpha$. Substituting in the preceding equation we find that the torque $= E_1 I \sin\gamma = A T \cdot I$.

Recapitulation. The motor characteristics (Fig. 7) are essentially determined by the ratio $O A$ to $A B$ of the effective stator and rotor ampere-turns, and by the brush shift angle α. The direction of the vector of current I is always along the axis of abscissae, that of the terminal voltage $O K$ approaches I as the speed increases. Select a value of I and plot $O A' = I$, remembering that $O A'$ does not represent the true direction of I in the time diagram, but only its magnitude. Then the following values are obtained:

Magnetizing current $O B' = I_m$

Stator voltage $O A = E_1$. It is found from Fig. 8 as the ordinate corresponding to abscissa I_m

Rotor voltage at standstill $A B = E_2$

Rotor voltage at slip s, $A C = s E_2$

Total useful voltage at slip s, $O C = E = \dot{E}_1 + s \dot{E}_2$ (geometric addition).

Reactive drop $C K'' = Ix$

Ohmic drop (which may be increased to cover core loss) $K''K = I r$

Terminal voltage $O K = \dot{P} = \dot{E} + \dot{I} x + \dot{I} r$

Slip $A''C'' = s$, where $A''B'' = 100$ per cent slip

Speed $C''B'' = \dot{1} - s$, where $A''B'' = 100$ per cent synchronous speed.

Input $K K' \cdot I$

Output $C C' \cdot I$

Efficiency $C C'/K K' = 1 - (K K''/K K')$

Power factor $\cos\phi = K K'/O K = O L'$, where $O Q = O L = 100$ per cent

Torque in synchronous watts $A T \cdot I$

E. The Secomor and its Use

The secomor (Fig. 9) is built out of four flat iron bars; these bars represent the principal vectors in Fig. 7. Each bar is provided with a centimeter scale, and they are mounted on an ordinary drafting board. A sheet of cross-section paper is tacked to the board and serves as a universal scale. The four bars and their functions are as follows:

(a) *The stator bar, $O A$*, determines the stator voltage E_1 and the current $O A' = I$ (Fig. 7)

(b) *The rotor bar, $D B$*, determines the rotor voltages E_2 and $s E_2$.

(c) *The speed bar, $D''B''$*, determines the slip s or the speed of the motor.

(d) *The setting bar, $C''L$* determines the point C for which the useful voltage E plus the impedance drop $C K$ gives the terminal voltage $P = O K$.

The setting bar is pivoted at O next to the cross-section paper, the stator bar is pivoted on top of it, and the other two bars slide on top of the stator bar. On each bar one edge is called the "reading" edge; on the pivoted bars the reading edge passes through the geometric center of the pivot O.

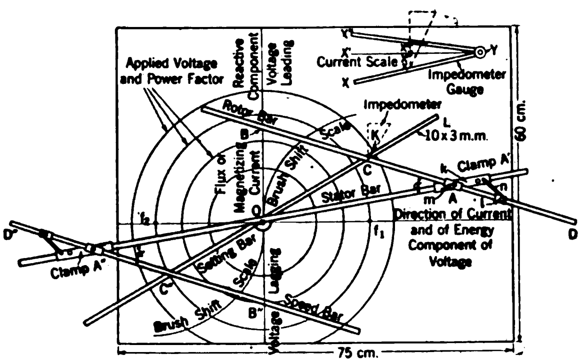

FIG. 9

The clamps A' and A'' have to be rather carefully made, to permit of an accurate setting and not to have too much lost motion. The long sleeve k of the clamp slides on the stator bar; the sleeves l and m guide the rotor bar as it slides in them. The sleeve m is pivoted on top of sleeve k; l is connected to k by means of a pivoted rod n. By tightening the set screw on k the rotor bar may be fixed at any desired point of the stator bar. By loosening the set screws on l and m the angle α can be adjusted, and after the screws have been tightened the angle remains constant. Part of each sleeve is cut out to enable one to see the scale and the reading edges of the bars.

It would be inconvenient to use a protractor for setting the rotor bar and the speed bar at a desired brush-shift angle α. Therefore, two large circular scales are provided on the base

of the apparatus, with centers on the axis of abscissae, at f_1 and f_2. These scales are marked in degrees and each is labeled in Fig. 9 "brush shift scale". To use the scale f_1 the stator bar is so turned that its reading edge coincides with the axis of abscissae; the clamp A' is shifted until the reading edge of the rotor bar passes through f_1. Then the rotor bar may be set at any desired angle. After the set screws on l and m have been tightened the angle remains unchanged when the clamp is shifted. The speed bar must be set at the same angle at f_2, and the two bars must always be parallel to each other when the secomor is in use.

The four concentric circles with the centers at O are used for the applied voltage. Any of them can be selected as a locus of point K. With some motor characteristics the bars are not long enough to be used with the largest circle and one has to use a smaller one. One of the circles is also used for reading the power factor (arc $N\,L\,Q$ in Fig. 7).

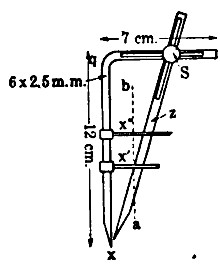

FIG. 10

The Impedance Triangle or the Impedometer (Fig. 10) is made of steel with two brass indicators, x' and x''. The inclined bar z is set for the desired ratio of r to x at synchronism and is fastened with the set screw S and with a clamp at the other end, not shown in the figure. The impedance drop is represented by the inner edges of the three bars. The lower indicator, x', is set for the desired value of $I\,x$ at synchronous speed, the upper indicator x'' is set for the value of $I\,x$ for standstill at the same current. The value of $I\,x$ for any sub-synchronous speed lies between x' and x'', and for super-synchronous speeds it lies below x'. These values can be readily estimated by the eye, the whole correction for the impedance drop being small. Point K (Fig. 7) lies somewhere on $a\,b$ (Fig. 10) but it is not necessary to have this line marked on the impedometer, because the device, when in use is lying on the cross-section paper with $x\,q$ parallel to one of the rulings (Fig. 9), and the eye easily follows the direction $a\,b$.

The two diverging straight edges X and X'' (Fig. 9) shown in the upper right-hand corner of the secomor serve as a guage for a quick setting of the impedometer. The horizontal line X' is one of the rulings on the cross-section paper, and serves as a current scale and the locus of the point x' of the impedo-

meter. Bar X is the locus for point x, and bar X'' is the locus for x''. The set screw Y fixes the bars in any desired position.

The saturation curve (Fig. 8) used with the secomor, is made out of a piece of ordinary solder wire, and can be readily bent and adjusted by hand to any desired shape. The lower end of the wire is held in a swivel clamp at O, and the upper end is clamped at R. The clamp R can be loosened and moved up and down in the slot T. The whole is mounted on a piece of board; a sheet of cross-section paper tacked to it serves as a universal scale.

The method of using the secomor follows directly from Fig. 7, the setting for different constants and for different loads being accomplished by shifting or turning the four bars. The reader can simply follow the "Recapitulation" above. As to the selection of scales for volts and amperes, the simplest method seems to be always to read everything directly in centimeters and to use constants afterwards. When testing an actual machine one usually reads the meters without regard to their constants, and later recomputes the data.

The use of the impedometer requires no particular skill or precision. Having located point C approximately near the chosen circle of applied voltage, the impedometer and the setting bar are shifted to and fro until the electrical condition for the sum of the voltages is fulfilled. This condition depends upon the speed which is simultaneously read at C''. Point K must always lie on $a\ b$ (Fig. 10), but its exact position on $a\ b$ is determined by the speed of the machine. At standstill it must lie on the intersection of $a\ b$ with the indicator x'', at synchronism it lies on the intersection of $a\ b$ with x'. At any other speed K divides $x'x''$ in the same proportion in which C'' divides $A''B''$. The length $x'x''$ being small as compared to $O\ C$ or $O\ K$, the judgment of the eye is amply sufficient. An engineer who uses the device regularly will soon find several short cuts which it is not necessary to mention here.

Conclusion

In presenting the secomor to the electrical profession the author wishes to point out the possibility of predicting the performance of the polyphase series commutator motor by means of a kinematic device. He also hopes to arouse interest in the use of similar kinematic devices for the prediction and analysis of performance of other types of electrical machinery. Besides the

secomor, he has designed the "shucomor" or a kinematic device which imitates the performance of a shunt-wound polyphase commutator motor, and as a by-product has obtained a device which gives the performance of the ordinary induction motor. Alternator characteristics can probably be imitated in a similar manner as well as those of single-phase commutating machines.

The usefulness of such devices is not limited to a-c. machinery, but embraces special cases of d-c. machinery as well. Sometime ago the author became interested in the operation of the Entz electromagnetic clutch and transmission used in some gasoline motor cars. He has built a kinematic device which imitates the performance of this ingenious clutch at different engine speeds and with any setting of the regulating resistances. The saturation curves of the two d-c. machines are also incorporated in the device. The device was demonstrated at the A. I. E. E. meeting in Syracuse, N. Y., in May 1917, and has been presented by the author to the Electrical Engineering Department of Syracuse University.

A kinematic device can no more replace human intelligence than a formula or a vector diagram can. But a mechanical device helps and guides an engineer's judgment, and makes it possible to achieve results with less time and trouble. One working on the design of the same type of electrical devices year after year finally attains some proficiency and needs but little outside help. But industrial efficiency demands that younger men do at least routine designing without much previous experience. A mechanical device makes it safer to entrust them with the determination of dimensions, because it enables them readily to check the performance. The effort of more gifted and mature engineers may thus be devoted to new developments and to large important problems, and less of their time need be occupied by the supervision over younger men. A wide use of mechanical devices that imitate the performance of electrical machinery is thus a step in the desired direction.

BIBLIOGRAPHY

The subject is covered quite thoroughly up to 1910 in E. Arnold's "Die Wechselstromtechnik," Vol. 5, part 2. The theory of both the series and the shunt-wound polyphase commutator motor has been principally studied in Germany, Austria, Switzerland and Sweden, and a few electric manufacturing companies in those countries have put such motors on the market. In France M. Latour has built some 10-pole motors as large as 500 h.p., with the armature connected 12-phase, and

with only one stud of brushes per pole, using a two-circuit winding. A brief note on these motors will be found in *La Lumière Electrique*, Vol. 29, p. 289.

A person interested in some phase of the subject should refer to the last volumes of the principal German and French electrical periodicals and search through the back volumes "counter-clockwise," until he has found the particular bit of information sought. For such a search the entry words in the indexes are probably much more valuable than a specific reference to a few articles. An entry word will enable the future investigator to locate in time articles yet unwritten. The magazines below are arranged in the order of their importance for the particular topic under discussion. The first two periodicals contain by far the largest amount and the best information. Of the American periodicals, *The General Electric Review* so far has been the only one in which original articles on the polyphase commutator motor have been published. *Science Abstracts* (London), part B, Electrical Engineering, is a most useful help in literature search on most any electrical subject.

Name of Periodical	Entry Word in the Index
Elektrotechnische Zeitschrift	Elektromotoren
Elektrotechnik und Maschinenbau	Kollektor, Kommutator, Mehrphasen
Archiv für Elektrotechnik	Name index, see Glossary below
General Electric Review	Motors
*La Lumière Electrique**	Machines, Moteurs

Glossary of German and French Terms for Facilitating Literature Search

English	*French*	*German*
machine	machine	Maschine
motor	moteur	Motor or Elektromotor
single-phase	monophasé	Einphasen or Wechselstrom
two-phase	diphasé	Zweiphasen
three-phase	triphasé	Drehstrom
commutator	collecteur	Kommutator or Kollektor
series-wound	série	Reihenschluss or Serien
shunt-wound	shunt	Nebenschluss

*Continued since 1917 as *La Revue Générale de l'Electricité.*

To be presented at the Sixth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 15, 1918.

A NEW STANDARD OF CURRENT AND POTENTIAL

BY CHESTER T. ALLCUTT

ABSTRACT OF PAPER

This paper describes a new secondary standard which is proposed as a substitute for the standard cell in certain classes of d-c. measurements. The device consists of a Wheatstone bridge which will balance for but one value of current.

Various factors affecting the accuracy and permanence of the device are discussed and a number of curves are given showing the characteristics which have been obtained.

THE increasing use of potentiometers in commercial service, especially in connection with the measurements of temperature by means of thermocouples, makes it very desirable to secure a substitute for the standard cell usually required by these instruments. The serious shortage of standard cells caused by the war has emphasized this need. Furthermore, it is being recognized that it is poor economy to use a costly precision standard in a commercial potentiometer which reads to three significant figures at the most.

In order to eliminate the standard cell from the type of thermocouple potentiometer used in measuring the temperature of electrical machines, it has become quite common practise to use a calibrated current-measuring instrument for setting the current. A long-scale galvanometer, in connection with a suitable shunt, is used as a deflection instrument for setting the current in the potentiometer circuit. After setting the current, the same galvanometer is used as a null instrument for balancing the thermocouple e.m.f. against the potentiometer. The chief objection to this practise is the fact that it necessitates the use of a very high-grade galvanometer. A long-scale galvanometer, suitable for use as a deflection instrument, is necessarily much more costly and more delicate than a short-scale instrument of the same sensitivity. For this reason it is desirable to provide a means for setting the current which will not

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only eliminate the standard cell but will also remove the necessity for a deflection instrument.

Description of Proposed Standard

The new standard which is proposed as a substitute for the standard cell in a certain classes of d-c. measurements is essentially a Wheatstone bridge which will balance for but one value

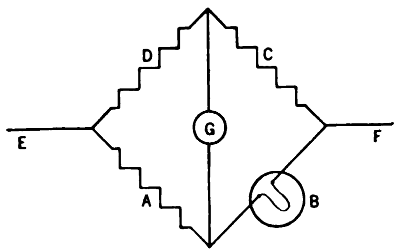

Fig. 1

of current. Referring to Fig. 1, the device consists of a Wheatstone bridge comprising three constant resistances, A, C and D and a fourth element B, whose resistance is a function of the current flowing through it. In practise, the resistance element B consists of an evacuated glass bulb which encloses a fine filament of a material having a relatively high temperature coefficient of

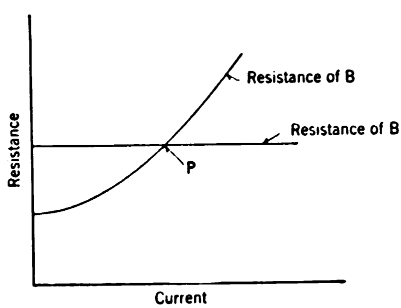

Fig. 2

resistivity. A galvanometer G is connected across the bridge and the leads E and F are connected to an external source of direct current (not shown). For the purpose of illustrating the action of the bridge, let us assume that the resistances C and D are equal. It is then obvious that the bridge will balance when the resistance of B is equal to the resistance of A. Fig. 2 shows graphically the relations involved. The bridge will balance

when the current through the branch A B of the bridge is equal to the abscissa of the point P. We thus provide a simple null method for setting the current in a circuit at a predetermined value.

The Variable Resistance Element—Construction and Characteristics

The practicability of the device depends on securing a variable resistance having the desired current-resistance characteristics, together with a high degree of permanence. For use with potentiometers, it is necessary to have the bridge balance at a rather low value of current, 20 milliamperes being the usual value for portable potentiometers. The necessary properties of the variable resistance element may be most readily obtained by using the construction already referred to; *i.e.*, a fine filament in a vacuum bulb. It was found possible to obtain resistances in this manner whose value would change very rapidly with small changes in current, even with currents of a few milliamperes. A number of bulbs have been made which would more than double in resistance when heated by the passage of 0.005 ampere. Fig. 3 shows a typical current-resistance curve of such a bulb. It will be seen that for currents of more than two milliamperes the resistance increases very rapidly with the current.

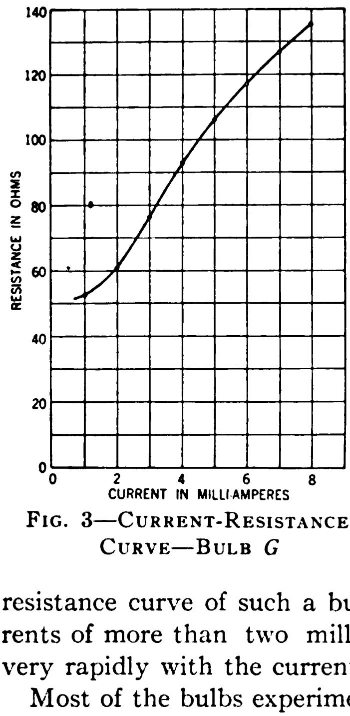

Fig. 3—Current-Resistance Curve—Bulb G

Most of the bulbs experimented with by the writer had platinum filaments approximately 0.0005 cm. in diameter and from 1 to 3 cm. in length. Silver coated platinum wire (Wollaston wire) was used, in order to facilitate the handling incident to the mounting the filament in place. After mounting the filament, the silver coating was removed by means of nitric acid, leaving the platinum core exposed.

The bulbs were evacuated to from 10^{-4} to 10^{-5} mm. of mercury. Past experience with high vacua has shown that even with pres-

sures as low as 10^{-5} mm., a very high degree of permanence may be obtained. Furthermore, at pressures as low as 10^{-4} mm., the change in heat conduction from the filament with changes in pressure is extremely small. In order to secure the permanence of vacuum referred to above, it is necessary to observe the usual precautions, such as heat treatment of the glass, etc., during the process of evacuation.

Another operation necessary for securing the requisite degree of permanence is "seasoning" the filament by passing, for a considerable time, enough current to heat the filament to a bright red heat. Twenty-four hours of seasoning was found to be

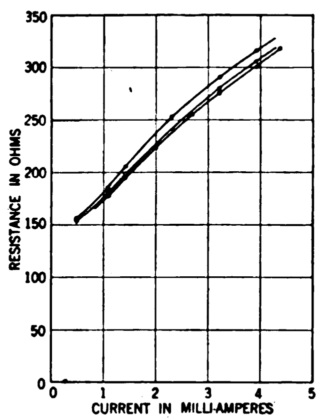

Fig. 4—Current-Resistance Curves

Curve A—New bulb.
Curve B—24 hours later.
Curve C—After 24 hours' seasoning.

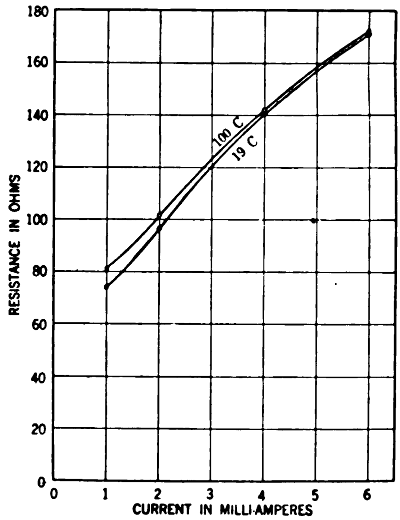

Fig. 5 — Current - Resistance Curves—Bulb *H*—Showing Effect of Ambient Temperature

ample. In every case the filament should be heated to a temperature considerably above the temperature at which it is to operate. Fig. 4 shows the effect of seasoning the filament on the characteristics of a bulb. Curve *A* shows the current-resistance characteristics of a new bulb. Curve *B* is plotted from data taken 24 hours later, while Curve *C* was taken after 24 hours seasoning. Further tests at a later date followed Curve *C* with great exactitude.

Another factor which might be expected to detract from the permanence of the bulbs is the possibility of a gradual change in the resistance of the filaments due to evaporation. As, in

every case, it is proposed to operate the filaments below red heat, no trouble from this source need be feared.

In order to observe the effect of ambient temperature on the current-resistance characteristics of a bulb, the data given in Table I were taken. Fig. 5 presents part of these data graphically. It will be seen that for the larger values of current the effect of ambient temperature is very small. For example, at six milliamperes the temperature coefficient is about 0.007 per cent per deg. cent. change in ambient temperature. For some classes of service this temperature coefficient is negligible. In any case, however, it may be exactly compensated for by giving one of the fixed resistances of the bridge with which the bulb is used a proper temperature coefficient, thus making the current for which the bridge will balance entirely independent of room temperature.

TABLE I—TESTS ON BULB H SHOWING EFFECT OF AMBIENT TEMPERATURES.

Temp. in oven	Current through bulb	Resistance of bulb
19°C.	0.001 amperes	74.08 ohms
19 "	0.002 "	96.5 "
19 "	0.004 "	140.6 "
19 "	0.006 "	171.1 "
44°C.	0.001 amperes	75.33 ohms
45 "	0.002 "	97.65 "
46 "	0.004 "	141.05 "
46 "	0.006 "	171.3 "
65°C	0.001 amperes	77.26 ohms
65 "	0.002 "	99.0 "
64 "	0.004 "	141.7 "
64 "	0.006 "	171.9 "
102°C.	0.001 amperes	81.05 ohms
101 "	0.002 "	101.5 "
100 "	0.004 "	142.0 "
100 "	0.006 "	172.1 "

The degree of permanence possible is shown by the data given in Table II. These data are the results of a series of observations on a bulb, covering a period of several weeks. It will be noted that for the smaller values of current there are differences in the values of the resistance that may be accounted for by differences in room temperature, while for larger values of current the effect of room temperature is apparently negligible.

Characteristics of New Standard

Figs. 6 and 7 show the sharpness of balance that can be obtained in a bridge using a bulb of the type described. These

TABLE II—RECORD OF TESTS ON BULB G.

Observation No.	Room temp.	Resistance at different values of current.				
		0.001	0.002	0.004	0.006	0.008 amperes
1	26.5	52.6	60.7	92.6	116.9	134.9
2	25.	52.5	60.6	92.5	116.8	134.9
3	23.5	52.2	60.4	92.5	116.9	134.9
4	24.	52.4	60.5	92.5	116.9	134.8
5	25.	52.5	60.7	92.7	116.9	134.9
6	24.	52.4	60.5	92.5	116.8	134.9
7	24.5	52.2	60.4	92.5	116.8	134.9
8	27.	52.4	60.5	92.6	116.9	134.9
9	27.	52.5	60.6	92.6	116.9	134.9

curves give the unbalanced voltage of the bridge (*i. e.*, the voltage tending to send current through the galvanometer) as a function of the current flowing through the bridge. The sharpness of balance may be increased by using two bulbs connected in opposite arms of the bridge, but it has been found that a sufficient degree of sensibility may be secured with but one bulb.

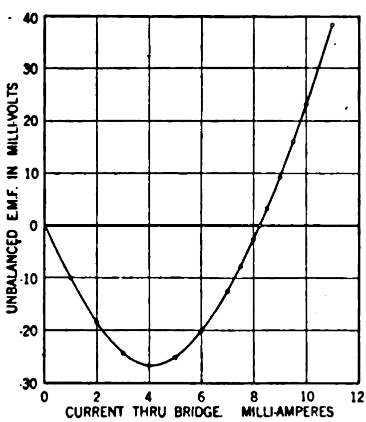

Fig. 6

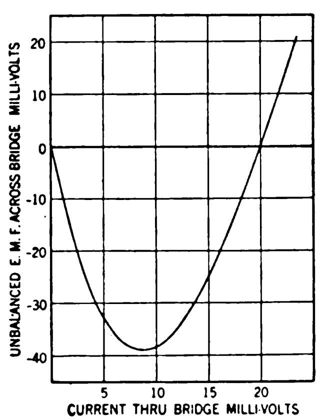

Fig. 7—Characteristics of Bridge Using Bulb *H*

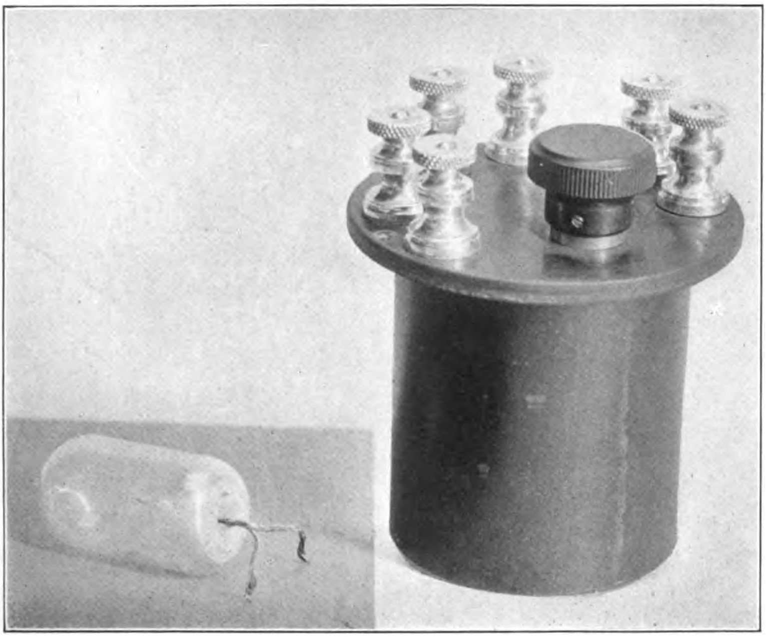

FIG. 8 [ALLCUTT]

Fig. 8 is from a photograph of the bridge whose characteristics are given in Fig. 7. This illustration also shows a bulb similar to the one used in constructing the bridge. The bridge was designed to balance with a current of 20 milliamperes. In addition, leads were brought out having just one volt potential difference between them when the bridge is balanced. A rheostat is mounted in the same box with the bridge. Fig. 9 is a diagram of connections of the device. In using this standard, a dry cell is connected to the binding posts marked *B* and a galvanometer at *G*. Then the rheostat is adjusted until the galvanometer shows no deflection. When the bridge has been balanced in this manner there is one volt between the terminals marked *E*. The instrument is thus a very simple standard of both current and e.m.f.

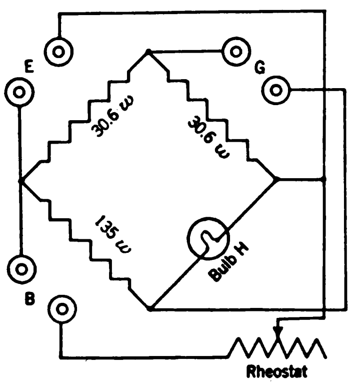

FIG. 9

For use with potentiometers, the current-setting bridge is permanently connected in series with the potentiometer circuit. Means are provided for throwing the galvanometer either across the bridge or in the circuit leading to the unknown e.m.f.

CONCLUSION

The work done in connection with the development of this new standard has demonstrated that it may be relied upon to maintain an accuracy of ± 0.1 per cent. The sensibility to current changes is ample, as it is very easy to set the current to within 0.1 per cent with the type of galvanometer usually supplied with portable potentiometers. The device may, therefore, be regarded as a suitable substitute for the standard cell for practically all classes of service outside of precision laboratory work

To be presented at the Sixth Midwinter Convention of the American Institute of Electrical Engineers, Feb. 16, 1918.

THE POLYPHASE SHUNT MOTOR

BY W. C. KORTHALS ALTES

ABSTRACT OF PAPER

There exists a demand for a reliable, adjustable-speed, alternating-current motor, suitable for operation at a large number of speeds. The neutralized motor with shunt field control is analyzed and it is shown that it is not practical for commercial frequencies on account of the expensive control equipment required. The induction motor with commutator on the secondary side is discussed. It may find some application for the larger outputs; the control is, however, still too complicated to make this type of motor suitable for the smaller machine-tool drives. The induction motor with commutator on the primary side offers the best solution for machine-tool motors. Its theory is discussed in detail, and a complete description is given of the mechanism required to shift the brushes and the new type of armature winding used.

INTRODUCTION

AS FAR as generation, transmission, distribution and constant-speed motor drives are concerned, the alternating-current system is far superior to the direct-current system.

The development of modern tungsten lamps, has practically done away with arc lamps, so that both systems are equally suitable for lighting.

The development of speed-regulating sets has made it possible to regulate efficiently the speed of induction motors up to several thousand horse power.

The varying speed alternating-current brush-shifting motors, which have recently been put on the market, can be applied to variable speed pumps, blowers, exhausters and certain textile machines.

The single-phase crane motor opens up possibilities in regard to dynamic braking, simplicity of control and operation over a wide range of speed, which cannot be met by the induction motor with resistance control.

The adjustable-speed alternating-current motor makes it possible in plants requiring adjustable-speed motors for machine

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tool, elevator service, etc., to use the alternating-current system throughout if desired, but due to the fact that the a-c. adjustable-speed motor is more costly than the d-c. adjustable-speed motor, it will be more economical to install machinery for changing over the alternating current to direct current, as long as a large number of motors is involved. However, the general tendency to standardization and centralization increases the number of processes which are carried on at constant speed and the call for the simple squirrel-cage induction motor and the use of the a-c. adjustable-speed motor, in cases where only a limited number is required, will make it possible to extend the application of the squirrel-cage motor.

It is not intended to deal in this paper with all the different types of a-c. adjustable-speed motors, which have been proposed by the various engineers that have worked on the problem. The paper will be limited to the types that now seem most important. It is of value to the specialist to know the large number of possible combinations, so that he can use them when the constantly varying conditions make this possible, but engineers in general need interest themselves only in those schemes which are at present suitable for practical application.

Neither is it necessary to discuss the multi-speed induction motor, the speed of which is adjusted by connecting windings wound with different numbers of poles to the line. The field of application and the theory of this motor is well-known. As long as only a few definite speeds are required, it is very satisfactory. However, there are a number of cases for which either a large number of speeds is required, or the desired speeds cannot be obtained with the possible numbers of poles. In those cases, one of the following types of alternating-current adjustable-speed commutator motors can be used. (1) The neutralized polyphase commutator conduction motor, (2) the induction motor with commutator on the secondary side, (3) the induction motor with commutator on the primary side.

The Neutralized Polyphase Commutator Conduction Motor

This motor consists of a d-c. armature winding, on the commutator of which is arranged a polyphase system of brushes, connected to a neutralizing winding which neutralizes the magnetomotive force of the armature winding, and is connected to the line. The field winding is connected to the secondary of

a transformer, the primary of which is connected to the line. It can be arranged in the same slots as the neutralizing winding, in which case the leakage flux will induce in the field winding a voltage proportional to and in phase with the leakage reactance voltage in the neutralizing winding. The motor field flux in this case lags ninety degrees behind the vector difference of the line voltage and the reactance drop induced in the field winding by the primary leakage flux which is yielded by the ampere-turns of both the field and neutralizing winding. The characteristics of the motor can be determined by considering that the neutralizing winding has no reactance drop, but that a reactance equal to the reactance of the neutralizing winding has been connected between the line and the motor terminals to which both the neutralizing winding and the field winding are connected. The field winding excites a rotating field, so that at synchronous speed the armature voltage and the voltage in the armature coils short-circuited by the brushes is zero, while this voltage increases when running above or below synchronous speed.

The field winding can also be arranged in other slots than those of the neutralizing winding. The field flux in this case lags ninety degrees behind the applied line voltage and the reactance drop of the neutralizing winding should be added to the reactance drop of the armature winding, which means that the difference between the no-load and full-load speed will be greater than before. The neutralized motor with the field winding in the same slots as the neutralizing winding is to the one with the field winding in other slots, as the direct-current shunt motor with resistance in series with the entire motor is to the direct-current shunt motor with resistance in the armature winding. This can be seen from the vector diagrams.

Fig. 1 gives the vector diagram for the neutralized motor with the field winding in the same slots, as the neutralizing winding. $O\,M$ represents the current which flows through both the neutralizing and the armature winding. $N\,O$ the current in the field winding. Assuming that the field winding and neutralizing winding have the same number of turns w_1, then the primary leakage flux will be yielded by $N\,M \times w_1$ ampere-turns and the reactance drop $A\,B$ induced by the leakage flux in both the neutralizing and field winding will lag ninety degrees behind $N\,M$. The resistance drop of the field winding, $F\,B$ is opposite to the field current $N\,O$. $F\,O$ is the voltage induced in the field

winding by the alternation of the field flux. $A\,B$, $B\,F$ and $F\,O$ balance the applied line voltage $O\,A$. For the circuit consisting of the neutralizing and armature winding in series, we find that the applied line voltage $O\,A$ is balanced by the leakage reactance drop $A\,B$ of the neutralizing winding, the resistance drop $B\,E$ of the neutralizing winding which is opposite to the current $O\,M$, the reactance drop $E\,D$ of the armature winding lagging 90 deg. behind $O\,M$, the resistance and brush-drop of the armature winding $D\,C$ opposite to the current $O\,M$ and the counter e.m.f. $C\,O$, which is induced by the field flux yielded by the field winding in space quadrature to the phase under consideration, and is proportional to the speed, the number of armature turns and the field flux. Due to the pulsation of the field flux, a voltage $O\,F$ will be induced in both the neutralizing and the

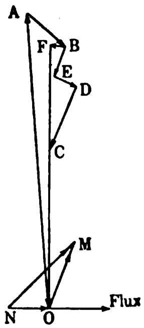


FIG. 1

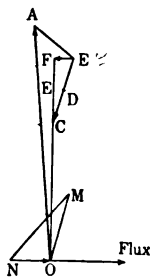


FIG. 2

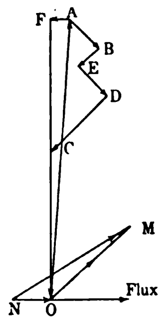


FIG. 3

armature winding. If the neutralizing and armature winding have the same number of turns, then the voltage in the armature winding will be neutralized by the voltage in the neutralizing winding and the resultant voltage appearing at the terminals will be zero. This voltage appears, however, when measuring the drop across the brushes and across the terminals of the neutralizing winding individually. The core loss has been neglected in the diagram. It causes the flux to lag behind the ampere turns. The output is proportional to $O\,C \times O\,M \times \cos\angle\, C\,O\,M$. Fig.1 has been drawn for operation below synchronous speed.

Fig. 2 gives the same diagram when the motor is running at synchronous speed. It has been drawn under the assumption that the leakage reactance of the armature is proportional to the slip. In that case, the rotor reactance is zero at synchronous

speed and the points D and E come together. The voltage applied to the field winding is equal to the vector connecting A with a point H on $C\,F$, so that $C\,H = F\,C$. This vector is not shown in Fig. 2.

Fig. 3 covers the diagram for a motor in which the field winding is located in other slots than those of the neutralizing winding. $A\,B$ lags now 90 deg., behind OM instead of $N\,M$ and the leakage flux yielded by the neutralizing winding does not induce any voltage in the field winding.

Fig. 4 is similar to Fig. 3, except that the motor is running above synchronous speed in which case the rotor reactance appears negative. The voltage to be applied to the field winding has not been shown, but can be found by connecting A with a point H on $F\,C$, so that $F\,H = \frac{n_0}{n}\,C\,C$, if n is the speed of the motor and n_0 the synchronous speed.

In case we take the load off the motors covered by Fig. 1, and Fig. 3 the speed will change as $O\,C$ to $O\,F$. Due to the location of the drop $A\,B$, the variation in speed will be larger in the latter, than in the former case. Hence, as far as the variation between the no-load and the full-load speed is concerned, it is better to arrange the field winding in the same slots as the neutralizing winding. However, by locating the field winding in other slots than those of the neutralizing winding, we can build the field winding with definite neutrals like a direct-current motor, so that in the coils short-circuited by the brushes, no voltage is induced by rotation through the main field flux. Moreover, we can locate at these neutral points, windings that excite the "Commutating Flux" inducing in the armature coils short-circuited by the brushes, a voltage which both neutralizes the voltage induced by the alternation of the field flux and furnishes the e. m. f. required to reverse the current in the coils passing the brushes. Furthermore, it is possible to improve the speed-torque characteristics by using a series transformer, the secondary of which is connected to the field circuit and shifts the time phase of the flux depending on the load current drawn from the line. The characteristics of this motor are particularly favorable when running far above synchronous speed. The diagram of Fig. 4 shows how the reactance of the neutralizing winding can be completely compensated by a negative reactance drop of the armature winding, but when predeter-

mining the characteristics, it must be borne in mind that the voltage induced by the commutating pole shifts the point at which the rotor reactance becomes negative to a higher speed, than in a motor which has no commutating poles.[1]

With the most generally used frequency of 60 cycles, it is impossible to take advantage of these favorable operating characteristics above synchronous speed unless we connect the motor to the secondary of an induction motor, in which case we can supply the commutator motor with both a low frequency and a low voltage and use it to control the speed of the induction motor. This has recently been done with great success and has led to a very important development of a-c. commutator motors. A discussion of the various connections and possibilities of this

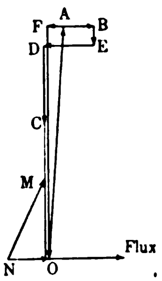


FIG. 4

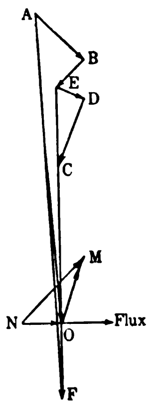


FIG. 5

application properly belongs to the subject of speed control of large induction motors and lies outside the scope of this paper.

The motor, with the field winding located in the same slots as the neutralizing winding, is more suitable for operation below synchronous speed and can be used directly on 60-cycle circuits. Instead of building it with a separate field winding, the neutralizing winding can serve at the same time as field winding which only slightly changes the diagram, as can be seen by comparing Fig. 1 with Fig. 5, which has been drawn for a motor in which both field and neutralizing winding have been combined in one. The vector AB is equal to the leakage reactance drop in the neutralizing winding which lags 90 deg. behind NM, BE is the resistance drop of the neutralizing winding, EF is the voltage

1. See H. Meyer-Delius, *General Electric Review*, 1913, page 976.

induced in the neutralizing winding by the alternation of the field flux, $F\,E$ the voltage induced in the armature winding by the alternation of the field flux, $E\,D$ the reactance drop, $D\,C$ the resistance drop, $C\,O$ the rotation voltage induced in the armature winding. The measured voltage across the neutralizing winding is equal to $A\;F$, the one across the armature winding reduced to the phase-voltage of the equivalent Y connection $F\,O$. The resultant of $A\;F$ and $F\,O$ gives the line voltage $A\;O$. Thus, we see that below synchronous speed, the voltage across the neutralizing winding is higher than the line voltage per phase until F and O are at the same point which occurs slightly below synchronous speed.

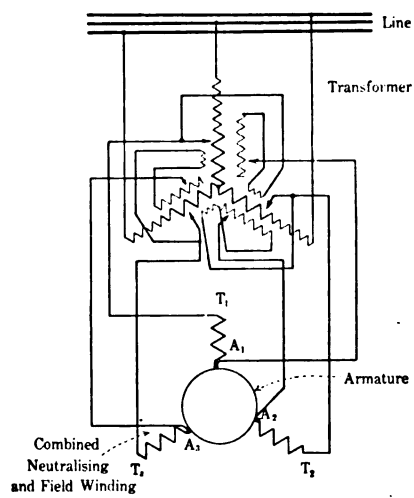


FIG. 6

The diagram of connections of a motor covered by the vector diagram of Fig. 5, has been shown in Fig. 6. Speed regulation can be obtained by connecting the terminals T_1, T_2, T_3 to different taps of the transformer which changes the terminal voltage applied to the motor, or by changing the points to which the armature terminals A_1, A_2, A_3 are connected, which changes the field flux, or by both. The principal disadvantage of this motor is that the transformer has to be designed for its full kv-a. capacity. In order to obtain satisfactory commutation, the armature must be built for a low voltage, which in general makes the ratio of the applied line voltage to the secondary voltage high, so that the size of the transformer is not materially reduced by building it

as a compensator. Instead of using the neutralizing winding also as field winding, the armature can serve for this purpose. Fig. 7 gives the diagram for this arrangement. In this case $O\ M$ is the current in the neutralizing winding, $N\ M$ the current in the armature winding. The volt-amperes required for exciting the field is equal to $F\ O \times N\ O$ of Fig. 7, instead of $A\ F \times N\ O$ of Fig. 5, as is the case when the field current flows through the neutralizing winding. As long as we are running at a lower speed than 50 per cent above synchronous speed, the field can be excited with less volt-amperes by using the armature, instead of the neutralizing winding, as field winding, which results in a small reduction in the size of the regulating transformer and an improvement of the power factor. It is also possible to excite

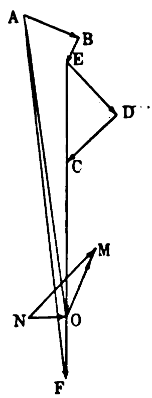


Fig. 7

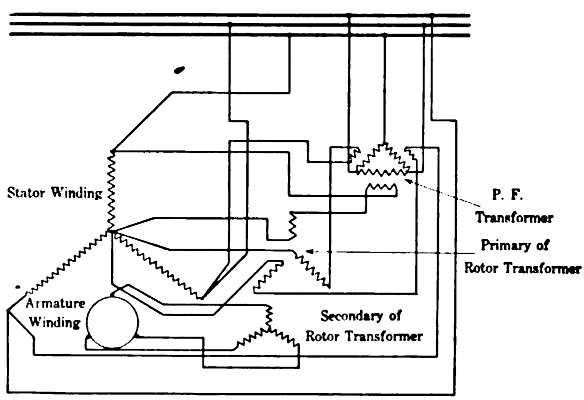


Fig. 8

the field by current flowing partly through the field winding and partly through the armature winding, which can be done by impressing voltage of the proper time-phase on both the neutralizing and the armature winding. However, all the above schemes, with the exception of the one where we connect the commutator motor to the secondary of an induction motor, have the disadvantage that a large transformer is required for the main circuit. The size of this transformer can be reduced by using the type of motor, which we will now describe.

Induction Motor with Commutator on the Secondary

In this type of motor, the armature reaction is neutralized by induction instead of by conduction. It is clear that the operation of the motor covered by Fig. 5 and Fig. 6 will not be changed,

if we separate the neutralizing winding from the armature winding provided we impress on the neutralizing winding the voltage $A F$ and on the armature winding the voltage $F O$. We can then increase the number of turns of the neutralizing winding, so that it can be connected directly across the line while the armature is connected to a rotor-transformer which supplies the voltage $O F$. We can take a brush-shifting series motor, put the brushes in the neutral and connect the primary of the rotor-transformer to different points of the stator winding. In this way, we get a motor which has the same characteristics as a neutralized motor, operated with a constant field flux and a variable voltage applied to the terminals.

Fig. 8 gives the diagram of connections which is suitable for a motor having four poles, or a multiple thereof. Four poles have been connected in series and a tap is brought out at each pole. (The taps have not been shown in the diagram.) This gives four speeds below and four speeds above synchronous speed, in addition to the synchronous speed, and requires thirteen stator terminals. The transformer should be built with a relatively low impedance drop, in order not to spoil the regulation. This can be done as long as only a small variation in speed is required. For instance, if we desire to regulate the speed 25 per cent below and 25 per cent above the synchronous speed, the capacity of the transformer is equal to only 25 per cent of the kilovolt amperes flowing through the motor. The characteristics can be improved by adding a small transformer by means of which the time-phase of the voltage impressed on the primary of the rotor transformer, is shifted.

On small motors, the rotor transformer can be omitted and the stator can be equipped with both a main winding connected to the line and a regulating winding connected to the armature winding. This can be done in various ways.[2]

In all the motors thus far described, the frequency of the rotor currents is reduced to line frequency by means of a commutator connected to the rotor winding, which makes it possible to combine the voltage induced in the rotor with a voltage derived from the line. It is possible to build a satisfactory motor in this way. However, the complicated control which it requires makes it rather unsuitable for the American market. The motor covered by Fig. 8 may find a limited application in special

2. See F. Eichberg, *Elektrotechnische Zeitschrift*, 1910, page 749; E. Arnold, *Die Wechselstromtechnik*, Bd. V2.

cases, although too complicated for general application to machine tool work.

The machine tool builders require an a-c. motor which can be installed as easily as a d-c. motor and the speed of which can be changed in a simple manner. In this respect, the next type of motor is more promising.

The Induction Motor With Commutator on the Primary Side

Instead of changing over the rotor frequency to the line frequency, we can add to the motor a frequency changer, which makes available at every speed a voltage of the same frequency as the voltage induced in the secondary. This can be done by taking a rotary converter armature, running in a laminated field and driven by the motor of which the speed must be regulated. If we connect the slip rings of the rotary converter to the line and select the number of poles and the speed ratio between the shaft of the motor and frequency changer in the proper way, the frequency of the voltage appearing at the commutator will be proportional to the line frequency times the slip. The ratio of the voltage applied to the slip rings to the one appearing at the commutator is independent of the speed. If we use two movable brush yokes connected to the secondary of the induction motor, by changing the relative positions of these yokes, we can impress on the secondary, voltages of different time-phase and amount and the speed of the induction motor can be regulated, both below and above synchronous speed. If c is the ratio of the number of turns of the winding of the converter to the secondary winding and n_0 is the synchronous speed, then the approximate speed range at no load varies between $n_0\,(1 - c)$ and $n_0\,(1 + c)$.

It is possible to combine the frequency changer and the induction motor, if we locate the induction motor primary winding on the rotor and connect it over slip rings to the line. In that case the frequency changer, which we will denote as regulating winding, does not need to be connected to the line, but its coils can be located on the rotor in the same slots as the primary winding, so that the primary flux induces the voltage in this regulating winding. The secondary is located on the stator and can be built with any number of independent phases, provided each yoke is equipped with the proper arrangement of brushes to correspond to this number of phases. The diagram

of connections of a motor of this kind, having three independent secondary phases has been shown in Fig. 9.[3] The brushes A_1, A_2, A_3, are mounted on one yoke and the brushes B_1, B_2, B_3 on another yoke. The motor will operate as an induction motor with short-circuited secondary when the brushes A and B are on the same commutator bar. Both yokes are moved 90 electrical degrees each way from this middle position, the yokes moving in opposite directions. In this manner, regulation both above and below synchronous speed can be obtained. The voltage across every commutator bar is independent of the speed and is proportional to the flux, the frequency and the number of turns in series. If we want to build a motor with the highest possible flux, without exceeding the safe limits for the voltage per bar, we should use a single-turn multiple armature.

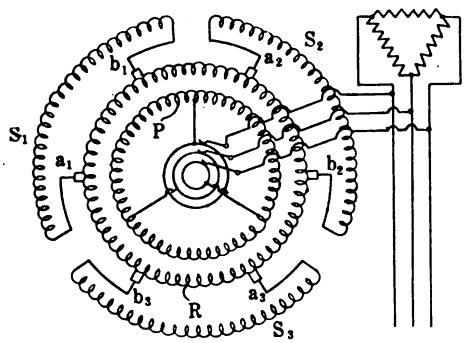


FIG. 9

But even with this winding, the maximum permissible flux is still low, so that this type of motor cannot be built for more than 5 h.p., per pole for 60 cycles and 12 h.p. per pole for 25 cycles, no matter what the speed range is, with the exception that the commutation below synchronous speed is sufficiently better than above, that if we do not make use of the above-synchronous speed range we can use a higher voltage per bar and a larger output per pole. In general, the small output per pole which can be obtained, is no serious draw-back, as most motors for machine tool and elevator work are geared and consequently built for low speed.

On the commutated induction motor with the commutator on the secondary side, the voltage across the commutator bars

3. This diagram is the one of the Schrage Patent 1,079,994.

is proportional to the flux, the number of turns and the frequency of slip. Therefore, if we build this motor for a small speed range, we can use a larger field flux and can obtain with 60 cycles and 20 per cent regulation above and below synchronous speed, 30 h.p. per pole and with 25 cycles, 75 h.p. per pole. This is only possible as long as the required starting torque is low, so that we can start the motor with reduced field flux to avoid excessive sparking.

On the commutated induction motor with commutator on the primary side, the voltage across the commutator bars at starting is the same as at running and high starting torque can be developed without any danger to the commutator. This fact makes this motor particularly suitable for reversible operation.

It has been explained above that it is possible to use a larger output per pole, by having the commutator on the secondary, instead of on the primary side. However, as long as we do not exceed the limitations of the output per pole and have 50 per cent regulation both above and below synchronous speed, it is much better, from a commutation standpoint, to use the second scheme. If we should build motors of the same output in both ways, we would naturally use equal field fluxes. This means that the regulating winding of the induction motor with the commutator on the primary side will have one-turn per coil, while the armature winding of the induction motor with the commutator on the secondary side will have two turns per coil. This will give the same sparking voltage at half speed and 50 per cent above synchronous speed for both motors.

It is clear that the commutation conditions, as far as the current commutation is concerned, are much better in the former case than in the latter, as we have a one-turn armature and a lower slot reactance, due to the fact that the regulating winding fills only part of the slots. The current commutation is the limiting feature above synchronous speed and for this reason, the induction motor with commutator on the primary side can be built for a larger speed range above synchronous speed than the one with commutator on the secondary side. This is a great advantage, because the speed-torque characteristics and the maximum output of the motor are much more advantageous above, than below synchronous speed. This partly offsets the limitation as to the maximum output per pole obtainable, as the reduction in speed resulting from the necessity of using a

large number of poles, is counteracted to a large extent by the possibility of raising the speed considerably more above synchronism.

The theory of the induction motor with commutator on the primary side can be explained with the aid of the same diagrams as have been given for the other motors. The following derivation of the diagrams made in a different way and some of the equations used in predetermining the characteristics, may be of interest.

In the approximate theory of the induction motor, the exciting

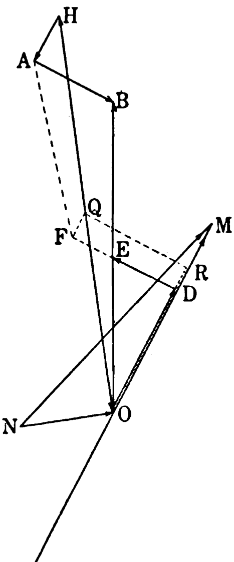


FIG. 10

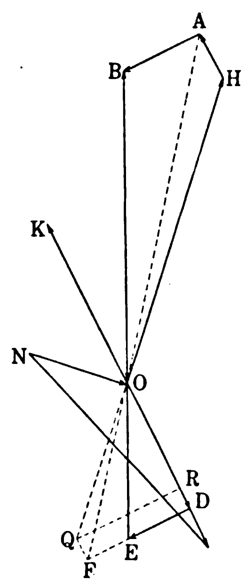


FIG. 11

current is considered constant[4], and as flowing through a separate exciting circuit. By doing this, a very slight error is made as we neglect the impedance drop of the exciting current, thus figuring with a flux which is slightly larger than the actual flux and we use, too high a value for the exciting current. The approximation simplifies the calculation considerably and will be used in the following. In Fig. 10, we have drawn the approximate vector diagram for the induction motor. We find for the primary circuit that the applied voltage $O\,H = E_t$ is balanced

4. See Steinmetz's Alternating Current Phenomena.

by the primary resistance and reactance drop $HA = I_0 r_0$ and $AB = I_0 x_0$ and the voltage $BO = E_0$ induced by the main flux. After having reduced secondary turns to the primary turns, we find that the same voltage $BO = E_1$ is induced in the secondary and that this voltage is balanced by the secondary reactance drop $DE = I_1 s x_1$ the secondary resistance drop $OD = I_1 r_1$, and the counter e.m.f., $EB = (L - s) E_1$. If we draw $QR \parallel FD$, $EF \parallel BA$ and $QF \parallel HA$ then $OQ = s E_l$

Let $OQR = i$ then $\tan i = \frac{OR}{QR} = \frac{r_1 + s r_0}{s x_1 + s x_0} = \frac{\frac{r_1}{s} + r_0}{x_1 + x_0}$

and

$$I_1 = \frac{E_l \sin i}{\frac{r_1}{s} + r_0}.$$

The torque per phase in synchronous watts equals

$$OB \times I_1 \times \cos \angle BOD = \frac{OD}{s} I_1 = \frac{I_1^2 r_1}{s}$$

The line current I_l is equal to the vector sum of I_1 and the exciting current I_m, which lags 90 deg. behind OH, provided we neglect hysteresis. Thus, the wattless component of the line current is equal to $I_{wl} = I_m + I_1 \cos i$ the watt component $I_1 \sin i$ and the total line current

$$I_l = \sqrt{I_m^2 + I_1^2 + 2 I_m I_1 \cos i}$$

When we drive the induction motor above synchronous speed as an induction generator, the diagram assumes the form of Fig. 11. The counter e.m.f. EB is now larger than the induced voltage BO. We have to take into account besides that the rotating field in the rotor has changed its direction, so that the time axis for the rotor rotates counter clockwise, while the time axis for the stator continues to rotate clockwise. For the counter clockwise rotating time axis of the rotor, the secondary reactance drop DE lags 90 deg. behind the current. This secondary reactance drop appears, however, as a negative reactance drop when reduced to the primary circuit in which the

time axis rotates clockwise.[5] A complete calculation of an induction motor in accordance with the above method has been given in Table I. It will be noted that this method is the same in principle as the approximate "Steinmetz method." The induction motor with commutator on the primary side can be calculated in a similar manner. If the primary and the regulating winding are located in the same slots, the leakage between these two windings is so small that it can be neglected. The vector sum of the ampere-turns resulting from the currents in both the primary and the regulating winding, will yield a leakage flux, which induces in the primary winding a voltage e_x and in

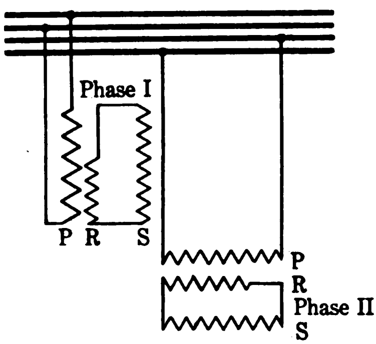


FIG. 12

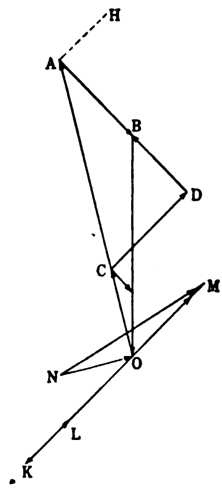


FIG. 13

the regulating winding a voltage $c\,e_x$ if c is the ratio of the number of turns of the regulating and the primary winding.

In order to find how the reactance should be taken into account, we can investigate the conditions at standstill and consider the motor as a quarter-phase stationary transformer having a primary winding, *P*, a regulating winding *R* and a secondary winding *S*. The windings *P* and *R* are fitted in between each other, so as to have only a small leakage between the two. *R* and *S* are connected together. Let *P* and *S* have the same number of turns, and the ratio of turns of *R* and *S* be *c*. If we assume as before that the magnetizing current flows in a separate

5. Dr. Rudenberg has called particular attention to this point in the *Elektrotechnische Zeitschrift*, 1910, page 1087.

TABLE I

s	0.01	0.0159	0.02118	−0.01	−0.0159	−0.02118
r_1	0.041575	0.041575	0.041575	0.041575	0.041575	0.041575
r_0	0.033778	0.03378	0.03378	0.03378	0.03378	0.03378
$\frac{r_1}{s}$	4.1575	2.619	1.968	−4.1575	−2.619	−1.966
$r_0 + \frac{r_1}{s}$	4.19275	2.6528	2.00178	−4.1238	−2.58522	−1.932
$x_0 + x_1$	0.2764	0.2764	0.2764	0.2764	0.2764	0.2764
$\tan i = \dfrac{r_0 + \frac{r_1}{s}}{x_0 + x_1}$	15.15	9.59	7.52	−14.9	−9.36	−6.98
i	86° 13′	84° 3′	82° 25′	273° 83′	263° ′53′	261° 51′
$\cos i$	0.0658	0.1036	0.1320	0.06685	0.1067	0.1422
$\sin i$	0.9978	0.9946	0.9912	−0.9977	−0.9943	−0.9899
El	317.5	317.5	317.5	317.5	317.5	317.5
$I_1 = \dfrac{El \cos i}{x_0 + x_1}$	75.6	119.0	151.5	76.5	122.2	163.2
or $I_1 = \dfrac{El \sin i}{r_0 + \frac{r_1}{s}}$	75.6	118.8	157.	76.8	122.	162.2
$D = \dfrac{I_1^2 r_1}{s}$	23,750	36,850	48,400	−24,400	−39,000	−51,800
I_m	59.6	59.6	59.6	59.6	59.6	59.6
$I_1 \cos i$	4.97	12.36	20.74	5.1	13.01	23.06
$I_{wl} = I_m + I_1 \cos i$	64.57	71.96	80.34	64.7	72.61	82.66
I_h	4.615	4.615	4.615	4.615	4.615	4.615
$I_1 \sin i$	75.4	118.1	155.8	−76.3	−121.1	−160.2
$I_w = I_h + I_1 \sin i$	80.015	122.715	160.42	−71.685	−116.48	−155.585
I_{wl}^2	4,165	5,170	6,450	4,200	5,280	6,835
I_w^2	6,400	15,010	25,750	5,150	14,700	24,190
$(I_w^2 + I_{wl}^2)$	10,565	20,180	32,200	9,350	19,980	31,025
$I_l = \sqrt{I_w^2 + I_{wl}^2}$	102.8	142	179.5	96.5	141.2	176.2
$P_1 = D\ (1 - s)$	23,500	36,250	47,400	−24,600	−39,600	−52,950
F_0	607	607	607	607	607	607
Mech. Output $= P = P_1 - F_0$	22,893	35,643	46,793	−25,207	−40,207	−53,557
Input $= I_w El$	25,400	38,900	50,900	−22,760	−36,980	−49,300
Eff. $= \dfrac{P}{I_w El}$	90.2	91.7	92.0	90.	91.9	92.1
P. F. $= \dfrac{I_w}{I_l}$	78.0	86.3	89.5	93.7	95.2	95.7
H. P. $= \dfrac{3P}{746}$	92.0	143.7	188.0	102.3	161.8	215.4

circuit, the ampere-turns yielded by P and R must be equal and opposite to the ampere-turns yielded by S. Hence, the current flowing in P of Fig. 12 is equal to $(1 - c)\ I_1$. Fig. 13 gives the vector diagram when neglecting the primary resistance drop. In the primary winding P, the line voltage $O\ A$ is balanced by the reactance drop $A\ B = I_1\ x_0$ and the induced voltage $B\ O$. The voltage across the regulating winding will be equal to $O\ C = c\ O\ A$ and we find that in the secondary circuit the induced voltage $B\ O$ is balanced by the reactance drop $D\ B$, the resistance drop $C\ D$ and the voltage $O\ C$ across the regulating winding. This voltage is the vector sum of the voltage induced by both the main and the leakage flux. The secondary current $O\ K = I_1$. The primary load current is equal to $-\ (O\ K - K\ L) = -(I_1 - c\ I_1) = O\ M$. We can add the exciting current $N\ O$ at right angles to $O\ A$ and find the

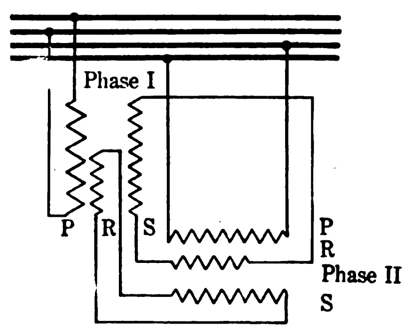


FIG. 14

line current $I_l = N\ M$. The secondary resistance drop $C\ D$ should include the brush drop and the resistance of both the secondary and the regulating winding. If desired, the resistance drop of the primary load current which is equal to $(1 - c)\ I_1\ r_0$ can easily be added, as shown by the dotted line $A\ H$. If $c = 0.5$, the primary load current is equal to $0.5\ I_1$ and the ampere-turns of the primary are equal to those of the regulating winding. In that case, the minimum copper loss will be obtained if we make the copper-cross-sections of both windings equal. When running above synchronous speed, the ampere-turns of the primary winding are equal to the sum of the ampere-turns of both the regulating and the secondary winding, hence in order not to have the primary winding overheat when running above synchronous speed, it is better to make the cross-section of the regulating winding smaller than those of the primary winding.

As $A\,C = (1 - c)\,E_l$, we can find the reactance $(x_0 + x_1)$ by an impedance test applying E_l to the slip rings

$$x_0 + x_1 = \frac{E_l\,(1 - c)}{O\,M} \sin \angle\, A\,C\,D$$

or approximately:

$$x_0 + x_1 = \frac{E_l\,(1 - c)^2}{I_l} \sin \angle\, A\,C\,D$$

It is clear that the condition described corresponds to the induction motor with the brushes in the neutral. We can also

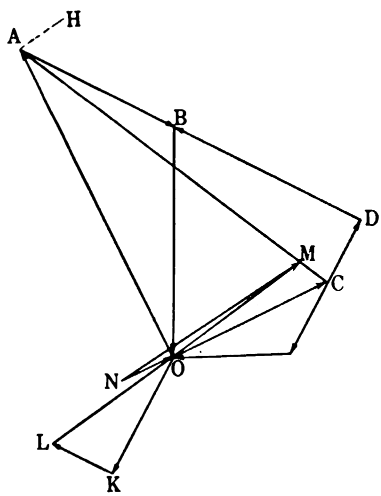


Fig. 15

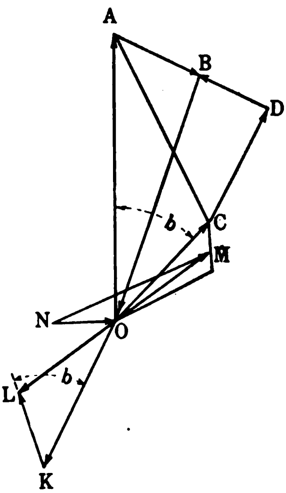


Fig. 16

connect the secondary of phase I to the regulating winding of phase II and the secondary of phase II to the regulating winding of phase I, as has been shown in Fig. 14. The vector diagram of this arrangement has been shown in Fig. 15. In this case, the resultant voltage, which overcomes the impedance drop, is equal to

$$A\,C = E_l \sqrt{1 + c^2}$$

and

$$x_0 + x_1 = \frac{E_l\,(1 + c^2)}{I_l} \sin \angle\, A\,C\,D$$

This corresponds to the commutated induction motor with a brush-shift of 90 deg.

Fig. 16 gives a similar diagram for a brush-shift (b) in which case the resultant voltage is equal to

$$A\,C = E_l \sqrt{1 + c^2 - 2\,c \cos b}$$

and

$$x_0 + x_1 = \frac{E_l\,(1 + c^2 - 2\,c \cos b)}{I_l} \sin A\,C\,D.$$

All the above equations for $x_0 + x_1$ have been given without taking the primary resistance loss, the core loss and the magnetizing current into account. This is satisfactory as long as the impedance test is made at greatly reduced voltage. If necessary, these values can be taken into account as follows: Read primary watts (W) amp., (I_l) volts (E_l).

Determine $I_w = I_l \cos \varphi$ and $I_{wl} = I_l$ sine φ.

Determine at standstill with open secondary I_m for a voltage E_l and subtract I_m from I_{wl} then the secondary current reduced to the primary is equal to

$$I_1 = \frac{\sqrt{(I_{wl} - I_m)^2 + I_w^2}}{\sqrt{1 + c^2 - 2 \cos b}}$$

The total secondary impedance is

$$z_1 = \frac{E_l\,(1 + c^2 - 2\,c \cos b)}{\sqrt{(I_{wl} - I_m)^2 + I_w^2}}$$

Let the core loss with E_l volts applied to the slip rings be W_c watts and the primary resistance loss with a current I_l, be $3\,I_l^2\,r_0$ then

$$r_1 = \frac{W - W_c - 3\,I_l^2\,r_0}{3\,[(I_{wl} - I_m)^2 + I_w^2]}$$

and

$$x_0 + x_1 = \sqrt{z_1^2 - r_1^2}$$

A comparison of Fig. 16 and Fig. 13 shows that due to the shift b, the secondary current $I_1 = O\,K$ is shifted into the direction of the secondary induced voltage $B\,O$. This means that with the same flux and the same secondary current, we get a higher torque. The possibility of shifting the time-phase of the secondary current by means of the brush-position, can be

utilized for obtaining a higher torque per ampere than is possible with the induction motor with resistance in the secondary. The fact that the secondary current at the same time flows through the regulating winding and thereby reduces the primary current, makes this condition still better.

Fig. 17 has also been drawn for a brush-shift b, only in this case the motor is running and a counter e.m.f. $E\,B$ is induced in the secondary. The resultant voltage in the secondary is equal to $E\,O = B\,O - E\,B$. If we draw $E\,F \parallel A\,B$ then

$$\frac{O\,F}{O\,A} = \frac{O\,E}{O\,B} = \frac{s}{1} \text{ or } O\,F = s\,E_l.$$

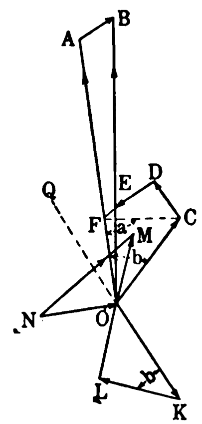


FIG. 17—RUNNING AS MOTOR BELOW SYNCHRONOUS SPEED—BRUSH SHIFT OPPOSITE TO DIRECTION OF ROTATION

Further $$F\,E = s\,A\,B = s \times x_0\,I_1.$$

$$F\,C = \sqrt{F\,O^2 + O\,C^2 - 2\,F\,O \times O\,C \cos \angle F\,O\,C}$$
$$= E_l \sqrt{s^2 + c^2 - 2\,c\,s \cos b}$$

Let $$\angle\, O\,F\,C = a \text{ and } \angle\, C\,F\,D = i$$

then $$\frac{\sin a}{O\,C} = \frac{\sin b}{F\,C} \text{ or } \sin a = \frac{c \sin b}{\sqrt{s^2 + c^2 - 2\,c\,s \cos b}}$$

$$\tan i = \frac{D\,C}{F\,D} = \frac{r_1}{s\,(x_0 + x_1)}.$$

The secondary current is equal to

$$I_1 = \frac{F\,C \sin i}{r_1} = \frac{E_l \sin i \sqrt{s^2 + c^2 - 2\,c\,s \cos b}}{r_1}$$

The torque per phase in synchronous watts is equal to

$$D = B\,O \times O\,K \cos \angle\, B\,O\,Q = O\,A \times O\,K \cos \angle\, A\,O\,Q$$

$$\angle\, A\,O\,Q = \angle\, O\,F\,C - (90^\circ - \angle\, C\,F\,D) = a + i - 90.,$$

or

$$\cos \angle\, A\,O\,Q = \sin (a + i)$$

and

$$D = E_l \times I_1 \sin (a + i)$$

The electrical output is equal to $P_1 = D\,(1 - s)$

The mechanical output (P) is equal to the electrical output minus the friction and windage per phase, $P = P_1 -$ friction, windage. The primary current can be calculated by determining separately the component I_w in phase with the applied line voltage and the component I_{wl} which is 90 deg. out of time phase with the line voltage.

If I_h is the core loss current then:

$$I_w = I_h + O\,K \cos \angle\, Q\,O\,A - L\,K \cos (\angle\, Q\,O\,A + b)$$
$$I_w = I_h + I_1 \cos (a + i - 90) - c\,I_1 \cos (a + i + b - 90).$$
$$I_w = I_h + I_1 [\sin (a + i) - c \sin (a + i + b)]$$

If I_m is the wattless component of the magnetizing current then,

$$I_{wl} = I_m + O\,K \sin \angle\, Q\,O\,A - L\,K \sin (\angle\, Q\,O\,A + b)$$
$$I_{wl} = I_m + I_1 [\cos (a + i) - c \cos (a + i + b)]$$

The total line current is $I_l = \sqrt{I_w^2 + I_{wl}^2}$

The power factor $= \dfrac{I_w}{I_l}$

The input $= E_l\, I_w$

The efficiency $= \dfrac{P}{E_l\, I_w}$

When determining the angles from the sine and tangent, some care must be taken to get the angle in the proper quadrant.

This can be done readily as long as the possible variation of these angles with the slip is taken into account, with the aid of the diagram. For instance, it follows from Fig. 17 that F moves over $A\ O$ from A to O when the slip changes from 1 to 0. The angle $C\ F\ O = a$ changes from an acute to an obtuse angle. Fig. 18 gives the diagram for the same brush position as used in the diagram of Fig. 17, when the motor is driven above synchronous speed. In case the motor is rotating counter clockwise, the field in the rotor will rotate clockwise. Hence, as long as we operate below synchronous speed, the electrical

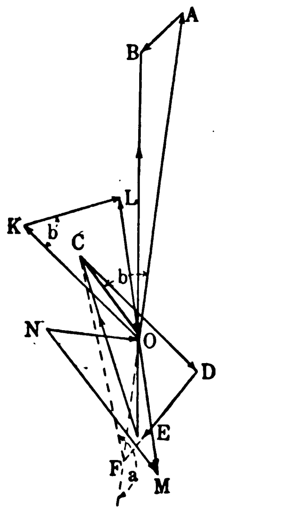


FIG. 18—DRIVEN AS GENERATOR ABOVE SYNCHRONOUS SPEED — BRUSH SHIFT OPPOSITE TO DIRECTION OF ROTATION

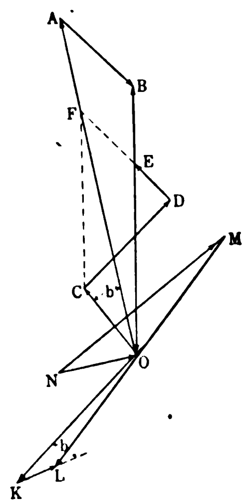


FIG. 19—RUNNING AS MOTOR BELOW SYNCHRONOUS SPEED — BRUSH SHIFT IN THE DIRECTION OF ROTATION

field will rotate clockwise, in respect to both the stationary secondary winding and the stationary brushes connected to the commutator of the regulating winding. This means that if we want $O\ C$ to lag behind $O\ A$, as shown in Fig. 17, we have to shift the brushes in the direction of the rotation of the electrical field, *i.e.* opposite to the mechanical rotation of the rotor. When running above synchronous speed, the electrical field will rotate counter clockwise, with respect to both the stationary secondary winding and the brushes and if we leave the brush position unchanged, we have to put $O\ C$ in the diagram ahead of $O\ A$, as has been done in Fig. 18. When running above

s.... ....
s^2........
c^2........
$s^2 + c^2$...
$2\ c\ s \cos b$
$s^2 + c^2 -$
$\sqrt{s^2 + c^2}$
$Eres = E$
$\sin a =$
a.........
$\tan i =$
i.........
$\sin i$.....
$I_1 = \frac{El}{}$
$a + i$....
$\sin (a +$
$D = El$
$P_1 = D (1$
Friction p
Mech. Ou
$a + i +$
$\sin (a +$
Ih.......
$I_1 \sin (a$
$Ih + I_1$ si
$I_1\ c \sin (a$
$Iw = Ih$
$\cos (a +$
$\cos (a +$
Im.......
$I_1 \cos (a$
$Im + I_1$ c
$c\ I_1 \cos (a$
$Iw = Im$
Iw^2......
Iwl^2.... .
$Iw^2 + Iw$
$Il = \sqrt{Iw}$
$P. F. =$
Input =
Eff. $= \frac{}{El}$

NOT

When (s)

When (s)

Tables I a

synchronous speed, the secondary reactance drop appears negative when viewed from the primary, as explained for the usual induction generator with short-circuited secondary. Table II gives a complete calculation made in accordance with the above theory. It has been found that the theory is confirmed by test.

Fig. 19 gives the diagram for a motor operating below synchronous speed when the brushes are shifted in the wrong direction, *i.e.*, in the direction of rotation. It will be noted that this results in a low secondary power factor, which is always

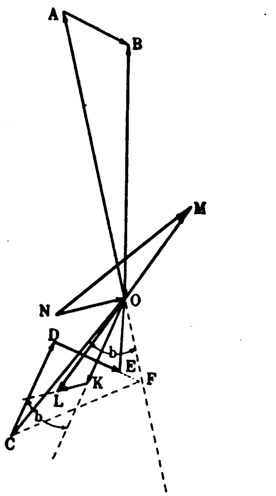


FIG. 20—RUNNING AS MOTOR ABOVE SYNCHRONOUS SPEED—BRUSH SHIFT IN THE DIRECTION OF ROTATION

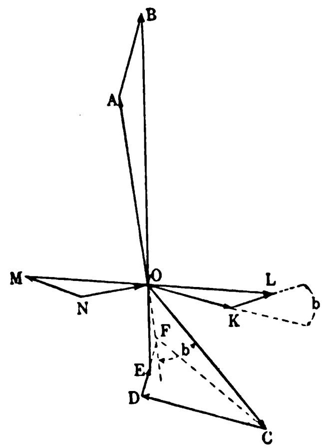


FIG. 21—RUNNING AS MOTOR ABOVE SYNCHRONOUS SPEED—BRUSH SHIFT OPPOSITE TO DIRECTION OF ROTATION

combined with a reduction in maximum output and larger variation between the no-load and full-load speed.

Fig. 20 gives the diagram for operation above synchronous speed. The counter e.m.f., $E B$ is larger than the induced secondary voltage $B O$ and the voltage $O C$ of the regulating winding is impressed in opposite direction, being shifted over an angle b in the direction of rotation from the neutral position.

Fig. 21 gives the same diagram, only the brushes are shifted opposite to the direction of rotation which causes the secondary current to lead too much and results generally in inferior commutation. Instead of calculating the characteristics by means

of simple geometrical equations, circle diagrams can be used.[6] Both the derivation and the application of these diagrams are rather complicated and, therefore, will not be given in this paper.

Fig. 22 gives the tested speed-torque curves of a 440-volt, 3-phase, 1200 rev. per min., 60 cycle-brush, shifting motor, built as an induction motor with the commutator on the primary side and on which the brushes are shifted 5 deg. opposite the direction of rotation in the slowest speed position and 5 deg. in the direction of rotation in the highest speed position. This has been done by shifting one yoke faster than the other, while both move in opposite direction, so that one yoke moves through 170 electrical degrees, while the other yoke moves through 190 electrical degrees. This motor has been built for one direction of rotation. If the motor has to operate with the same characteristics in both

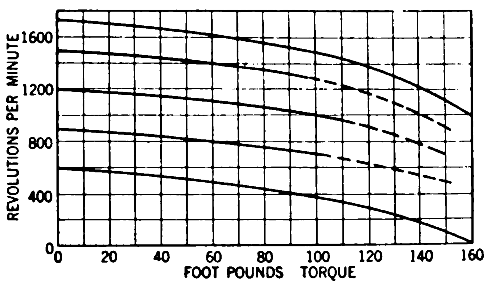


Fig. 22

directions of rotation, the brush-shifting mechanism becomes more complicated, as will be understood from Figs. 23 and 24, which give the desired brush-position for maximum and minimum speed in both directions of rotation for a two-pole motor. However, a simple mechanical solution has been found and a model incorporating this scheme is now being tested. A photograph of it is shown in Fig. 25, while the brush-shifting mechanism is represented in Fig. 26. This motor has been built with four-poles and a six-phase secondary, each yoke having 12 studs.

The fast moving yoke *B* on which the brushes *b*1, *b*2, *b*3 have been mounted, is supported by the bearing-housing. The slow moving yoke on which the brushes *a*1, *a*2, *a*3 have been

6. See O. S. Braystad, *E. T. Z.*, 1903, page 368; E. Arnold, *Die Wechselstromtechnik*, Bd. V2; H. Meyer-Delius, *General Electric Review*, 1914. page 817; H. K. Schrage, *E. T. Z.*, 1914, page 81.

mounted, is supported by the end shield; it is moved by means of a stud which connects it to the disk *C*, which is supported on the bearing housing. The pinions *D* and *E* are keyed to a shaft which can rotate in a bearing supported by the disk *C*. The pinion *D* meshes with a gear *F* which is mounted on the bearing housing and the pinion *E* meshes with a gear *G* which is fastened to

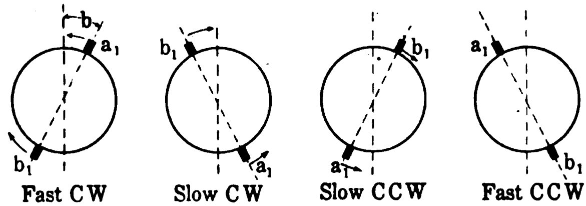


FIG. 23

b_1 moves through 360 − 2 *b* deg. *C W*
a_1 moves through 360 + 2 b deg. *C C W*. While b_1 moves through 2 *b* deg. from slow *C W* to slow *C C W*, a_1 should move *C W* through 2 b degrees

yoke *B*. If the gear *F* is held stationary and the disk *C* is turned, both opinions *D* and *E* will rotate. Pinion *E* will drive the gear *G* fastened to yoke *B*. The gear ratio can be selected in such a manner that disk *C* and yoke *A* move in opposite direction to yoke *B* and at a slower rate. The gear *F* is held by a pinion *H* which is keyed to the same shaft as the intermittent gear *I*, while this shaft rotates in a bearing which is rigidly supported

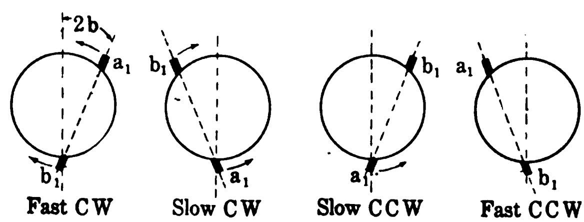


FIG. 24

b_1 moves through 360 deg. *C W*
a_1 moves through (360 deg. + 4 *b*) *C C W*. While b_1 moves through 4 *b* degrees from slow *C W* to slow *C C W*, a_1 should stand still

from the bearing housing. The intermittent gear *I* is moved through a small angle when it is struck by a pin, which is fastened to the disk *C*. After the pin has moved it, *I* is held stationary by sliding on the outside circumference of *C*. When *I* is moved by the pin, *H* will turn through the same angle and move the gear *F*. By properly selecting the gear ratios, it is possible, when we change from "Slow" in one direction to "Slow" in the other

direction, to have yoke B remain stationary or move in the same direction as C, while the intermittent gear is moved by the pin. The former arrangement gives a change of brush-positions in accordance with Fig. 24, the latter in accordance with Fig. 23. A control switch is connected to the shaft to which I is connected, and changes the phase-rotation of the lines to which the collector rings have been connected.

The induction motor with commutator on the primary side can be run single-phase, by opening one lead connecting to the collector rings. If only single-phase is available, it can be started like an ordinary single-phase induction motor by using a split-phase starting device, or as a repulsion motor, in which case a higher torque can be obtained. This connection is shown in Fig. 27, for a motor having a quarter-phase secondary.

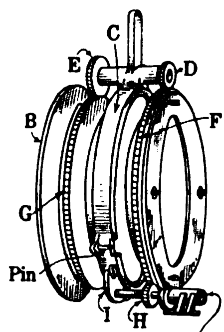


FIG. 26

One phase of the regulating winding is used as the primary of the repulsion motor, a resistance R keeps the line current down and the connections are changed from starting to running, by means of a three-pole double-throw switch. If the motor has a three-phase secondary, a four-pole double-throw switch is required.

In its original form, the induction motor with commutator on the primary side is wound with the primary winding in the bottom and the commutated regulating winding in the top of the armature slots. In this way, four coil ends have to be inserted in every slot, which takes up much room for the insulation. Moreover, if the primary winding has to be repaired, it is necessary to remove first part of the coils of the regulating winding. A winding is being developed which is arranged in such a manner

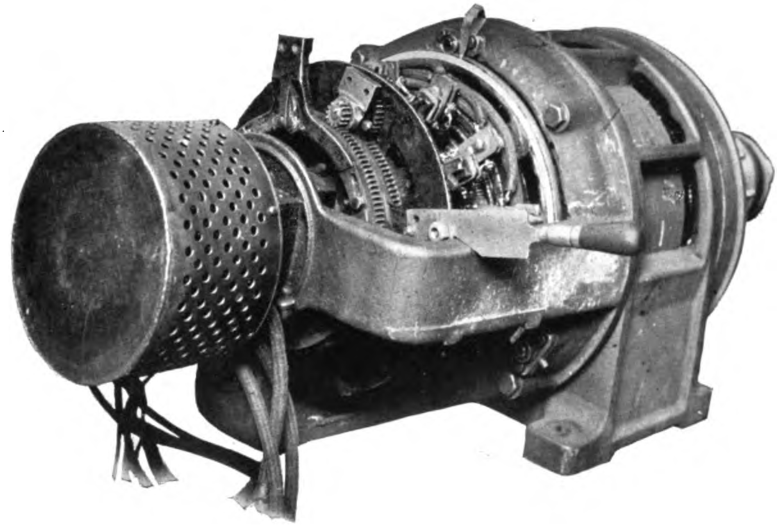


FIG. 25

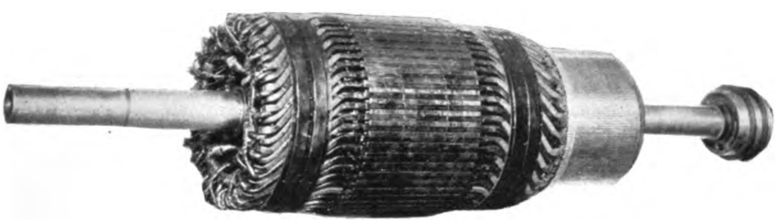
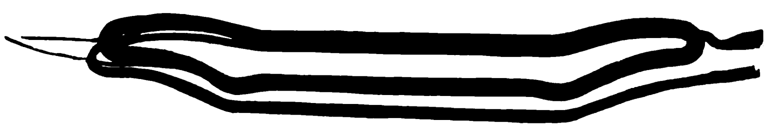


FIG. 28



[ALTES]

FIG. 29

that only two coil ends are located in one slot. If we have an even number of slots and use a coil pitch equal to an odd number, we can arrange the windings in such a way that we get a primary coil in the top of every odd and in the bottom of every even slot, and a coil of the regulating winding in the top of every even slot and in the bottom of every odd slot.

The leads of the primary winding can be brought out on the back end and the leads of the coils of the regulating winding on the commutator end. The insertion of such a winding is no more difficult than the insertion of an ordinary lap winding, it merely being necessary to have two kinds of coils. By doing

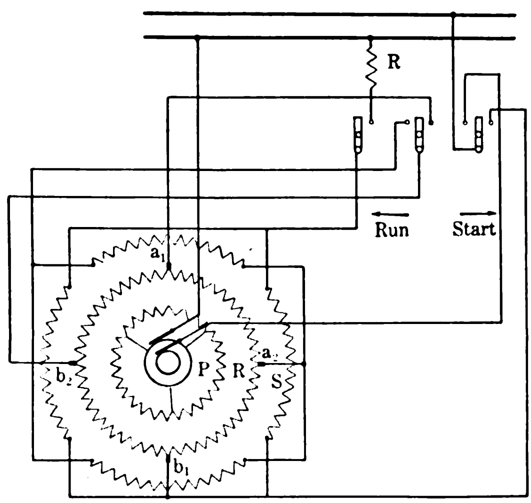


FIG. 27

this, we require half the number of coils and save room in the slots. Fig. 28 shows a photograph of a completed armature and Fig. 29 one coil of the primary and one coil of the regulating winding of a 220-volt, 750-rev. per min., 25-cycle motor with this new type of winding. The coils are inserted into open slots which are closed by a magnetic wedge. It will be noted that the coil of the regulating winding is lighter than the one of the primary winding, and that a slight bend has been added to each end of the lower straight part of the primary coil, in order to make room for the upper half of the next primary coil.

The regulating winding is a closed commutated winding with one coil per slot. The coils should always be connected in such

a manner, that we get a balanced mesh connection without internal short-circuiting current. We can obtain this condition, by making the coil pitch equal to an odd number of slots. This has been shown in Fig. 30, in which we have an odd number of

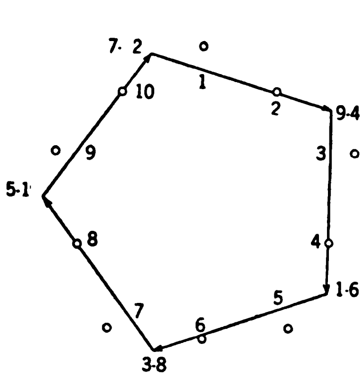


Fig. 30

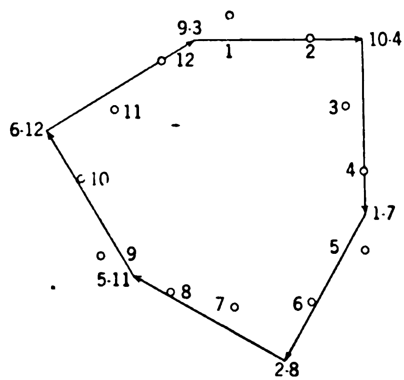


Fig. 31

slots per pole (5), the coils being full pitch slot 1 to 6. The coil ends have been represented by hollow dots. The vectors 1-6, 3-8, 5-10, 7-12, 9-4, represent the values of the induced voltages in the coils 1-6, 3-8, etc., when this armature is

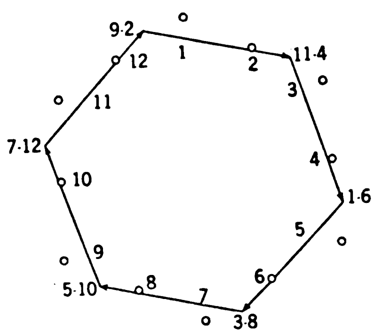


Fig. 32

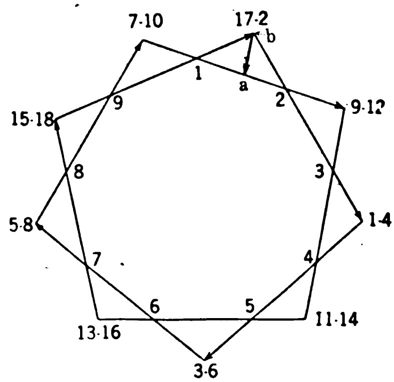


Fig. 33

surrounded by a rotating field. The resultant voltage of all the coils is zero, which means that we will have no circulating current The same result could have been obtained with a coil pitch 1-4, 1-2, 1-8, 1-10.

In Fig. 31, we have an even number of slots per pole (6) and a

coil pitch equal to an even number of slots. This results in a balanced winding, since the coils have been arranged in groups of two, so that we get the same effect as though we had an odd number of slots per pole (3). This arrangement is possible, if the number of slots per pole is equal to an odd number times an integer.

In Fig. 32, we have an even number of slots per pole. This gives also a balanced winding, as long as the coils span an odd number of slots (5). We could also have used a coil pitch 1-4, 1-2, etc.

Fig. 33 gives the vector diagram for a four-pole armature having (18) slots, *i. e.*, $4\frac{1}{2}$ slots per pole. Slot 1 is in the same time-phase as slot 10, slot 2 as slot 11, etc., so that we can use one potential circle. The coil pitch is 1-4. We have $4\frac{1}{2}$ coils for

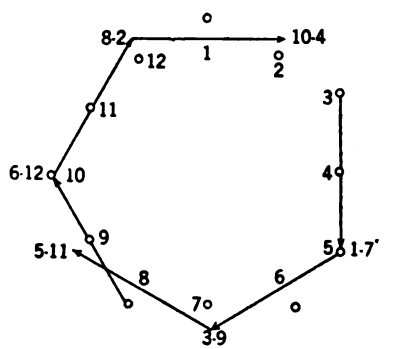


FIG. 34

every two poles. Even if we have two commutator bars per coil, we would not get zero voltage between the beginning of coil (1-4) and the middle point of the 5th coil (9-12), but the vector difference would be equal to *a-b*. However, all nine coils together give zero voltage, so that we can use this arrangement either as a four-pole series armature, or as a four-pole multiple armature, without equalizers. If we put on equalizers, a voltage equal to *a-b* would be short-circuited. Neither is it advisable to use bus rings in this case, and we should wind the secondary which connects to the brush-studs, with two separate circuits per phase

Fig. 34 is an arrangement which would tend to a large circulating current, and in which we have an even number of slots per pole and a full pitch coil. If we use (10) commutator bars

and (2) conductors per slot in all the slots with the exception of slot 5, 11, 6 and 12, in which one conductor per slot should be used, we get a closed polygon and can use this winding.

From Figs. 30, 31, 32, 33 and 34, it follows that the regulating winding can be wound with one coil per slot, as long as certain conditions are fulfilled.

We may now investigate which numbers of slots give a satisfactory primary winding. In order to get a balanced winding without excessive local leakage, it is necessary to have one coil end of the primary winding in every slot. This is possible only when the total number of primary slots is even. The coil ends belonging to the different phases, should be inserted in the same order; otherwise the phase rotation will be reversed on some parts of the circumference. This limits the use of fractional pitch coils for the primary to certain special cases, which will be described below.

The following general rules can be formulated which make it possible to determine whether a certain number of slots is suitable for a primary winding of a given number of poles and phases. (*a*) The total number of slots should be even. (*b*) To get a regular winding, the number of slots per pole, should be divisible by the number of phases $d = \frac{s}{2\,p \times n}$ = integer. (In which $2\,p$ = number of poles, n = number of phases.) (*c*) To get a balanced winding, the total number of slots should be divisible by two times the number of phases $b = \frac{s}{2\,n}$ = integer.

If we want to find whether a satisfactory winding can be obtained, we can proceed as follows:

$$\text{Determine } e = \frac{s}{2\,p} \quad \text{and } b = \frac{s}{2\,n}$$

Case 1. If e = odd number, make the coil pitch equal to e and connect primary so as to get b slots per phase and an equal number of slots per pole. (For regulating winding, see Fig. 30.)

Case 2. If e = even number, see whether e has an odd factor c and if so, make coil pitch equal to e and treat $\frac{e}{c}$ coils like under 1. (For regulating winding, see Fig. 31.)

Case 3. If e = even number, determine $\frac{s}{2\,p\,n} = d$ = number of slots per pole per phase. If d is even, then make coil pitch equal to $\frac{s}{2\,p} \pm 1$ and connect as under 1. (For regulating winding, see Fig. 32.) If d is odd, it is impossible to get a balanced winding.

Case 4. If e is a mixed number, see whether $\frac{s \times f}{2\,p}$ gives an integer in which $f = p$, or $f < p$ and $\frac{p}{f}$ = integer. This gives an irregular winding, while the regulating winding, if connected as a multiple winding, can have equalizers which span $2f$ poles,

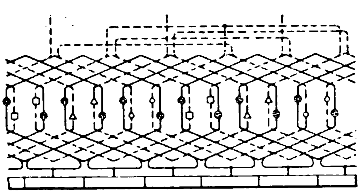


FIG. 35

instead of two-poles. If $p = f$, then we can have no equalizers. (For regulating winding, see Fig. 33.)

In all the above cases, we will get a balanced winding only when $b = \frac{s}{2\,n}$ = integer.

A few examples may make it clear how the above rules can be applied.

Case 1. The armature shown in Fig. 28 may be mentioned as an example; it has four poles, three phases and sixty slots. $e = \frac{60}{2 \times 2} = 15$; $b = \frac{60}{2 \times 3} = 10$ and $d = \frac{60}{2 \times 2 \times 3} = 5$.

Case 2. As an example may be mentioned the 60-slot, 6-pole, 3-phase winding used on the 10-h.p. motor, the speed-torque curves of which are covered by Fig. 25. In this case we have: $e = \frac{60}{2 \times 3} = 10$; e has an odd factor $e = 5$, while $\frac{e}{c} = \frac{10}{5} =$

2. The pitch of the primary coil is equal to 10 slots, $\frac{e}{c} = 2$, coils are treated as a single-coil.

Case 3. A 48-slot, single-pole, quarter-phase armature can be wound in this way,

$e = \frac{48}{2 \times 3} = 8$; $d = \frac{48}{2 \times 3 \times 2} = 4$. The coil pitch is equal to $e - 1 = 7$. As another example

Fig. 35 represents the diagram of both the regulating and the primary winding wound with two poles, three-phases and twelve slots. $e = \frac{12}{2} = 6$; $b = \frac{12}{2 \times 3} = 2$, and $d = \frac{12}{2 \times 3} = 2$.

Case 4. The scheme covered by this case is suitable for a 60-slot, 8-pole, 3-phase armature.

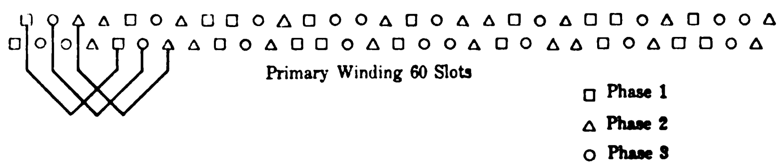


FIG. 36

$$e = \frac{60}{2 \times 4} = 7.5;\ d = \frac{60}{2 \times 4 \times 3} = 2.5,$$ *i. e.*, the winding is irregular, so that we have to use alternately 2 and 3 slots per pole.

$$b = \frac{60}{2 \times 3} = 10,$$ *i. e.*, the phases are balanced.

By making $f = 2$, we get $\frac{s\,f}{2\,p} = \frac{60 \times 2}{8} = 15$.

The equalizers should span $2f = 4$-poles and each phase of the secondary should have two independent circuits. An examination of Fig. 36, which covers the arrangement of the phases of this winding, will show that this arrangement repeats itself every 30 slots, which means that equalizers spanning 30 slots, *i. e.*, four-poles will connect slots of equal potential, with respect to the primary winding. From Fig. 33, it follows that these

equalizers are also permissible, as far as the regulating winding is concerned.

A 60-slot armature is particularly suitable for this type of winding, as it can be wound with 2, 4, 6, 8, 10 and 12 poles. It is possible to use the same commutator and brush rigging for motors having 4, 6, 8 and 12 poles, by building the secondary with 6, 4, 3, and 2 phases, respectively. This leads to a reduction in the number of required mechanical parts for motors of different frequencies and speeds, which is very advantageous from a manufacturing point of view, and will make this type of motor less costly as soon as there is a sufficient demand for it.

To be presented at the Sixth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 15, 1918.

MEASUREMENT OF POWER LOSS IN DIELECTRICS OF THREE-CONDUCTOR HIGH-TENSION CABLES

BY F. M. FARMER

ABSTRACT OF PAPER

This paper describes the method used at the Electrical Testing Laboratories for measuring the dielectric power losses in 10-foot samples of three-conductor cables with three-phase potential applied to the cable. The difficulties encountered and the methods employed to overcome them are discussed in considerable detail. Typical results are given in the form of data for two specimens of cable, one having a low power loss in the dielectric and one having a high power loss in the dielectric. The data are also presented in the form of curves.

The discussion includes:

(a) The theory of excessive internal dielectric loss as accounting for cable failures at local "hot spots."

(b) The advantages of plotting data with logarithmic scales.

(c) A comparison of results obtained by computation from single-phase measurements with those obtained by direct measurement with three-phase potential.

The conclusions drawn are:

(a) The power loss in the dielectric in a three-conductor cable under actual three-phase conditions can be readily measured in the laboratory with specimens ten feet lnog.

(b) No special apparatus is necessary for such measurements other than a reflecting high sensitivity wattmeter.

(c) Apparently the power loss in the dielectric cannot in all cases be accurately calculated from data obtained in single-phase tests although it is highly probable that for all practical purposes the discrepancy would not be serious. Further investigation is necessary, however, before final conclusions on this point can be stated.

(d) While the method of determining power losses in the dielectric directly by three-phase measurements involves more complication in preparation and slightly more time in the actual measurements, it has the important advantage that the results are conclusive and not subject to the uncertainty which pertains to results calculated from single-phase measurements.

THE CARRYING capacity of a cable is determined by the temperature at which the dielectric strength becomes dangerously low or at which deterioration takes place at an abnormal rate. If the temperature which the materials in the cable will safely withstand is known, the carrying capacity of the cable is fixed when the hottest part of the cable reaches this limiting temperature.

Manuscript of this paper was received January 22, 1918; released for publication January 22, 1918.

Until two or three years ago the only factors which had been given serious consideration in determining the temperature of the cable were the $I^2 R$ losses in the conductor and the thermal conductivity of the surrounding media. In other words, it was assumed that the copper loss was the only source of heat that need be considered and that the temperature which would be reached would depened simply upon the amount of heat thus generated and the rate at which this heat was carried away. However, careful investigations of cable failures, for which there was no obvious explanation, seemed to indicate that there were local hot spots which were not due to any outside cause. Attention was then drawn by investigators of insulation problems to the possibility of power losses in the insulation being responsible for abnormal temperature rises. Investigations made by Hochstadter[1], Clark and Shanklin[2], Bang and Louis [3] and others indicated that, under operating conditions which could be considered as normal, these losses might become sufficiently high to raise the temperature of the insulation to the destruction point. The subject of power loss in cables has therefore been attracting much attention and it is particularly pertinent at the present time because of the necessity for operating cables at the maximum possible capacity in order to meet the demand for more power. Furthermore, the amount of the power loss in dielectrics, although small, may in the aggregate be sufficiently large to justify consideration from the economic standpoint when new installations are contemplated at the present prices of materials and labor.

Object of Paper. The object of this paper is to describe the methods used in making tests at the Electrical Testing Laboratories for the purpose of determining the power loss in the dielectric of samples of paper-insulated, lead-covered cables 10 feet long, the loss being measured at various voltages and various temperatures. While nothing absolutely new or particularly novel is presented, it is felt that some detailed information in regard to these tests may be of service to engineers who will be called upon to make tests of this character.

1. M. Hochstadter—"Twisted Cable," *Electrotechnische Zeitschrift*, November 25th, 1915, page 617.

2. W. S. Clark and G. B. Shanklin—*Insulation Characteristics of High-Voltage Cables*, PROCEEDINGS A. I. E. E., June, 1917, page 465.

3. A. F. Bang and H. C. Louis—"The Influences of Dielectric Losses on The Rating of High-Tension Underground Cables," PROCEEDINGS A. I. E. E., June, 1917, page 449.

The power loss in the dielectric of three-conductor cables is probably most frequently determined by making single-phase measurements and then computing the corresponding three-phase loss on the basis of certain assumptions. That is, the power loss in the dielectric between the conductors (conductor loss) and the loss between the conductors and the sheath (belt loss), is measured with single-phase potential at the appropriate Y or delta voltage. The loss with three-phase potential is then calculated on the assumption that these two losses are the same with three-phase potential as with single-phase potential and that their sum is the total loss. Hochstadter[4] pointed out the possibility of this assumption being open to question because of the complex nature of the electrical field in the insulation between the conductors when subjected to three-phase potential.

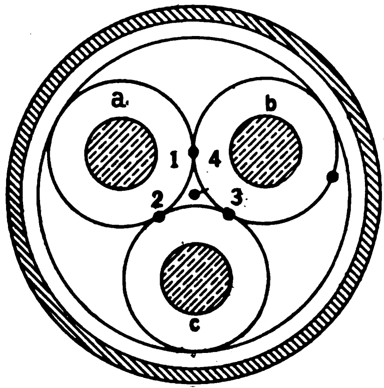


FIG. 1

Referring to Fig. 1 which represents diagrammatically a cross-section of a three-conductor cable, the dots 1, 2 and 3 indicate the points of contact between the various conductor insulations on lines connecting the centers of the three conductors. The dot 4 is the center of the cable and may in three-phase operation, be assumed to be at ground potential. If delta potential, E, is applied to the three conductors, a, b and c, the potential between different points will be as follows:

$$\text{Volts } a-4,\ b-4,\ c-4 = \frac{E}{\sqrt{3}}$$

$$\text{Volts } a-1,\ b-1,\ a-2, \text{ etc.} = \frac{E}{2}$$

4. M. Hochstadter—"Twisted Cable," *Electrotechnische Zeitschrift*, November 25th, 1915, page 617.

In other words, points 1, 2 and 3 are not at the same potential and therefore there is a tangential electrical stress in the insulation between the conductors which does not exist when making single-phase measurements. Consequently there is a power loss in the dielectric in this part of the cable insulation which would not be determined by such a measurement.

That the loss per unit volume of insulation between conductors may be actually higher than elsewhere, is suggested by evidences found by Clark and Shanklin and others in their investigations of cable failures,—that is, the insulation between the conductors was charred although the insulation between the conductors and sheath was apparently uninjured. As it is well known that the power loss in most insulations increases rapidly with temperature, it seemed logical to suspect that the loss per unit volume, and therefore the heat generated in the insulation between conductors, had increased faster than it could be dissipated, with the result that the temperature rose to the destruction point.

Because of the doubt which these considerations cast upon the method of determining the power loss in the dielectric of three-conductor cables from single-phase measurements, it was considered advisable to measure the power loss directly under three-phase conditions. Incidentally, however, single-phase measurements were also made, so that some interesting comparative data were obtained.

Method Employed. The method used in these tests was the simple three-wattmeter method for measuring three-phase power. That is, the cable was Y-connected, with the sheath as the neutral, and a wattmeter was connected to each phase in turn. The algebraic sum of the three quantities thus obtained is, of course, the total power dissipated. The high potential which was applied to the cable was obtained with three 15,000-volt, 200-watt, potential transformers connected in Y. The wattmeter was a reflecting dynamometer instrument, the current circuit being connected between the grounded neutral point and the high-tension winding of the transformer in the phase being measured, while the potential circuit was connected to the low-tension winding of a step-down potential transformer connected across the same phase.

The actual measurements were not, however, accomplished as easily as this description might indicate despite the simplicity of the general method. In the first place, the power factor is

as low as four or five per cent at moderate temperatures. Consequently, the effect of inductance in the potential circuit of the wattmeter and the phase angle in the step-down potential transformer is very marked and would produce serious errors if not properly taken into account. In the second place, the voltages used are so high and the power being measured so very small (as low as one watt) that losses through paths in parallel with the cable, that is leakage losses to ground from the test circuits, are likely to be relatively large and great care must be taken to eliminate them.

The effect of the inductance in the potential circuit of the wattmeter and the phase angle of the potential transformer was eliminated by the usual method of shunting a variable portion of the series resistance with a condenser as indicated in the diagram in Fig. 2. Thus the resultant equivalent inductance of

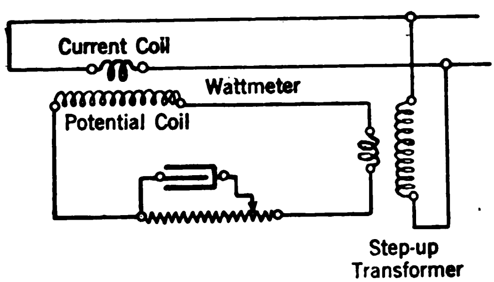


FIG. 2

the circuit is compensated for by the introduction of a proper amount of capacitance. Exact compensation can be determined by the following methods:

(a) Measure the inductance of the wattmeter potential circuit and the phase angle of the transformer. Then compute the capacitance and shunt resistance necessary from the relation $L = C R^2$, where L is the equivalent inductance of the circuit in henrys, C the capacitance of the condenser in farads and R the shunt resistance in ohms. This method requires a very careful measurement of the phase angle of the transformers, a measurement which involves either special apparatus or standardized transformers.

(b) Connect a high-voltage air condenser as the load in place of the cable and adjust the resistance which is in shunt with the condenser until the wattmeter shows no deflection. The accu-

racy of this method depends upon the power factor of the condenser. Normally an air condenser may be assumed to be a perfect condenser and therefore have zero power factor, but at high potentials the corona discharge from the circuits and from the condenser plates may introduce a power component unless great care is taken in the construction and proper means are provided to eliminate this corona discharge. However, when done in the careful manner employed by Shanklin[5] it is probable that this method is the best one for adjusting the compensation.

In the tests discussed in this paper, the compensation was determined by method (a) and checked by method (b), slightly modified. It was not found possible, with the only apparatus available to eliminate leakage entirely from the test circuits and consequently the deflection of the wattmeter could not be reduced to zero. The compensation was therefore so adjusted that connecting various amounts of capacitance to the circuit

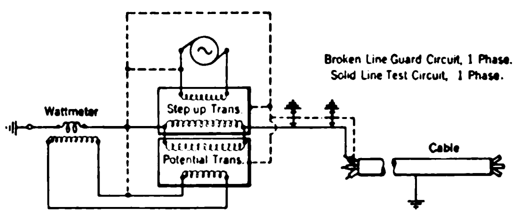


FIG. 3

did not change the deflection. Incidentally, this capacitance was obtained by suspending from the test circuit a number of metal cans about six inches in diameter and 15 inches deep, which were conveniently at hand. Since the adjustment could be made at potentials well below the part where corona discharges would take place from these cans, it was not necessary to take special precautions on this account.

As previously stated, the cable was tested by applying Y voltage to the conductors, the lead sheath being connected to the neutral and to ground. Obviously, all points of contact with each high-tension circuit provided leakage paths to ground in parallel with the insulation of that particular conductor of the cable, so that the power measured at the terminals of the high-tension winding of the transformer would include the

5. G. B. Shanklin, "Compensated Dynamometer Wattmeter Method of Measuring Dielectric Energy Loss," *General Electric Review*, Vol. 19, page 842 (1916).

power expended in these leakage paths. A guard circuit was therefore provided for each of the three phases as indicated by the broken lines in Fig. 3 which shows diagrammatically the arrangement for one phase. This guard circuit consisted of a metallic connection between each of the following:

(a) A piece of tin or tin-foil inserted between ground and each insulator supporting the high-tension circuit, moderate insulation being provided between the metal and ground.

(b) A few turns of fine bare copper wire around the insulation of the conductor about two or three inches from the end (the lead and wrapper insulation of the cable having been cut back several inches in the usual manner to permit separation of the ends of the conductors) which served to pick up any leakage current over the surface of the insulation between the conductor and the lead.

(c) The iron cases of the step-up power transformer and the step-down potential transformer, the transformers being insulated from ground.

(d) The low-tension windings of the transformers. This is necessary because it would be possible for a leakage current to pass from the high-tension winding to the low-tension winding of the transformers as well as to the cases.

(e) A point *between the wattmeter and the grounded end* of the step-up power transformer.

This guard circuit arrangement theoretically eliminates any current from the wattmeter current circuit that does not pass through the insulation of the cable except, of course, that directly through the air due to corona. In these tests, however, the potentials were always below the corona value.

As previously stated, it was not found possible to eliminate leakage currents entirely but it is probable that they were entirely due to insufficient insulation between all parts of the guard circuit, including the circuits to which it is connected, and ground. In fact, there was a partial ground in one phase of the generator which necessitated connecting the low-tension side of the power transformer to ground instead of to the guard circuit. Consequently leakage from the high-tension winding to the low-tension winding of the power transformers could not be properly shunted by the guard circuit.

A special smooth-core generator was used in these tests and oscillograms made under test conditions showed that the wave shape was substantially a sine curve under all conditions.

Suitable switching arrangements were provided so that the current circuit of the wattmeter could be quickly shifted from one phase to another and a similar provision was made for changing the potential circuit from one phase to another. Fig. 4 shows diagrammatically the circuits used in the test and the switching arrangements employed.

Power Measurements. The power in each phase was measured as already indicated, the total power to the test circuits and the cable being taken as the algebraic sum of these three measurements. The cable was then disconnected from the high-tension leads, leaving all of the rest of the test circuits exactly the same,

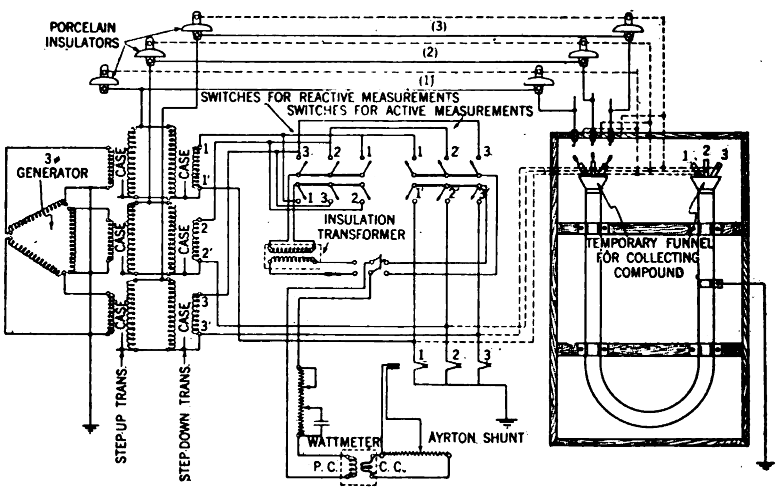


FIG. 4—DIAGRAM OF CONNECTIONS FOR DIELECTRIC POWER LOSS MEASUREMENTS—THREE-CONDUCTOR CABLES WITH THREE-PHASE POTENTIAL

and the measurements repeated. The latter gave the "leakage" loss. The difference between these two quantities was taken as the power loss in the dielectric of the cable.

Power Factor. The power factor was obtained by measuring the reactive volt-amperes. This measurement was made by simply shifting the voltage circuit of the wattmeter through 90 degrees by connecting to the proper delta voltage instead of the Y voltage.

Direct-Current Resistance. The resistance between the various combinations of conductors and lead sheath was measured in the usual manner with a sensitive reflecting galvanometer at 700 to 800 volts.

Capacitance and Alternating-Current Resistance. These quantities are obtained by computation from the above data,—the alternating-current resistance from the power and the capacitance from the reactive volt-amperes.

Heating of Cable. The heating of a section of cable 10 feet long to a temperature as high as 125 deg. cent. uniformly throughout its length is not the simple problem that one might expect. The first scheme considered appeared to be a very simple solution until it was tried. A sheet iron pipe about 10 inches in diameter with the cable suitably supported at its center was constructed and low-voltage current circulated through the pipe. It was expected that this scheme would give uniform heating, provide convenient control of the temperature and make the determination of the temperature of the cable a relatively easy matter because of the symmetrical arrangement of heat source with respect to the cable. The first difficulty experienced was the heating at the joints in the pipe due to the greater electrical resistance at these points. Also, there was an excessive cooling at the ends. The pipe was then wrapped with asbestos and a layer of iron wire wound thereon and through this wire current was circulated—additional turns being provided at the ends to compensate for the cooling effect. This scheme was satisfactory insofar as obtaining uniform temperature conditions was concerned, but it was found that at the high temperatures too much compound was being lost from the cable at the ends. It was therefore evident that some provision had to be made to prevent this loss of compound.

The iron pipe was abandoned and a simple oven was constructed consisting of a wood box lined with asbestos of such a size that the cable when bent in the form of a U having about 2.5 feet radius could be mounted in the box in a vertical position. The expansion of the compound was taken care of by soldering a sheet tin funnel to the lead at each end of the cable and into this funnel the compound could expand on heating and flow back again into the cable on cooling. Heat was provided by large incandescent lamps so located by experimental trials as to give the most uniform temperature, two fans being installed to assist in attaining this condition. Switches outside of the box provided control of the amount of heat being supplied and therefore of the temperature.

The temperature of the cable was measured by seven thermocouples soldered to the lead sheath. No difficulty was found in

getting these thermocouples to agree within 3 deg. cent. at a temperature of 100 deg. cent. One of the couples was connected to a curve-drawing instrument for the purpose of conveniently showing when a cable had reached constant temperature with

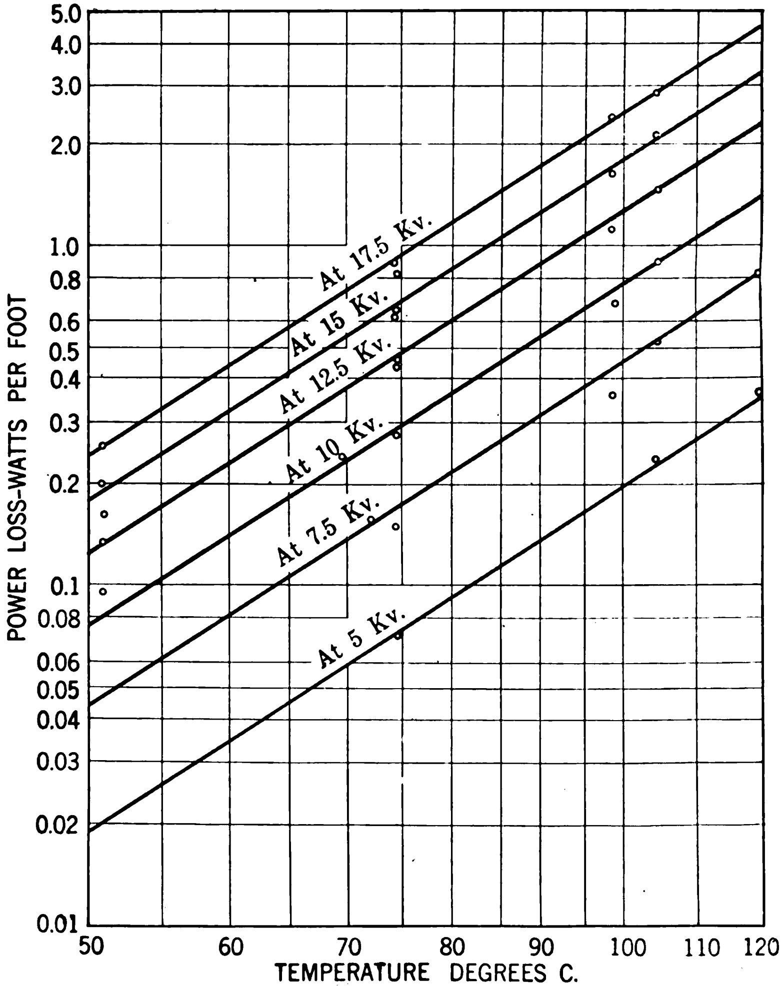


FIG. 5—POWER LOSS VS. TEMPERATURE AT VARIOUS TEMPERATURES—CABLE *A*—(LOGARITHMIC SCALE)

any given condition of heating. The final test of thermal equilibrium was the wattmeter indication, the power loss in the dielectric, being very sensitive to temperature. Final loss measurements were not taken until the wattmeter indication had been constant for at least thirty minutes.

Typical Data. While this paper is primarily a discussion of the method of measurement of dielectric losses in cables, it is

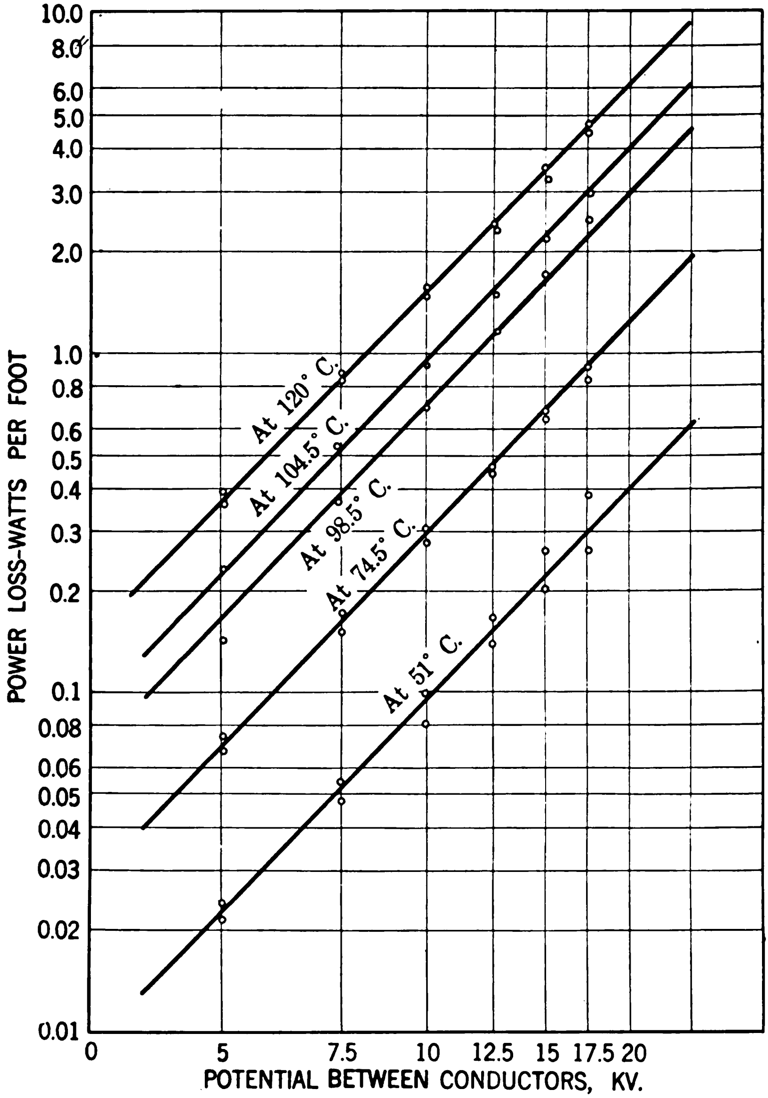


FIG. 6—POWER LOSS VS. VOLTAGE AT VARIOUS TEMPERATURES—CABLE *A*—(LOGARITHMIC SCALE)

thought that some typical data which have been obtained will be of interest. Table I gives summaries of the power loss in the dielectric and power-factor data for two cables, one having a

TABLE I.

CABLE A, LOW LOSS

(a) *Power Loss in dielectric, watts per foot.*

Temperature deg. cent.	Kilovolts between conductors					
	5	7.5	10	12.5	15	17.5
50	0.02	0.045	0.076	0.125	0.18	0.24
60	0.035	0.082	0.14	0.23	0.33	0.44
70	0.058	0.14	0.235	0.385	0.55	0.74
80	0.092	0.215	0.37	0.60	0.83	1.15
90	0.135	0.32	0.55	0.90	1.25	1.70
100	0.19	0.45	0.78	1.28	1.80	2.45
110	0.27	0.63	1.08	1.75	2.50	3.40
120	0.35	0.84	1.40	2.35	3.30	4.40

(b) *Average Three-Phase Power Factor**

Temperature, deg. cent.	Power factor, per cent
50	3.5
60	6.5
70	10.5
80	15.
90	21.5
100	31.
110	41.
120	52.

CABLE B, HIGH LOSS

(a) *Power Loss in dielectric, watts per foot.*

Temperature deg. cent.	Kilovolts between conductors					
	5	7.5	10	12.5	15	17.5
50	0.07	0.18	0.30	0.49	0.74	1.06
60	0.16	0.32	0.58	0.93	1.40	2.00
70	0.22	0.55	0.98	1.60	2.45	4.45
80	0.36	0.89	1.60	2.60	3.85	5.55
90	0.58	1.35	2.40	3.90	5.85	8.35
100	0.78	1.95	3.50	5.70	8.50	12.3
110	1.10	2.75	4.95	8.00	12.0	17.2
120	1.50	3.75	6.65	10.8	16.2	23.2

(b) *Average Three-Phase Power Factor**

Temperature, deg. cent.	Power factor, per cent
50	10.
60	21.
70	32.5
80	44.
90	55.5
100	66.
110	72.
120	75.

*Computed from ratio of total three-phase watts to total three-phase reactive volt-amperes, the figures given being the average for all voltages.

much higher loss than the other. The data as actually obtained on samples 10 feet long are shown graphically in Figs. 5 to 11 inclusive—the first four being curves plotted with logarithmic scales and the last three with arithmetical scales. The figures

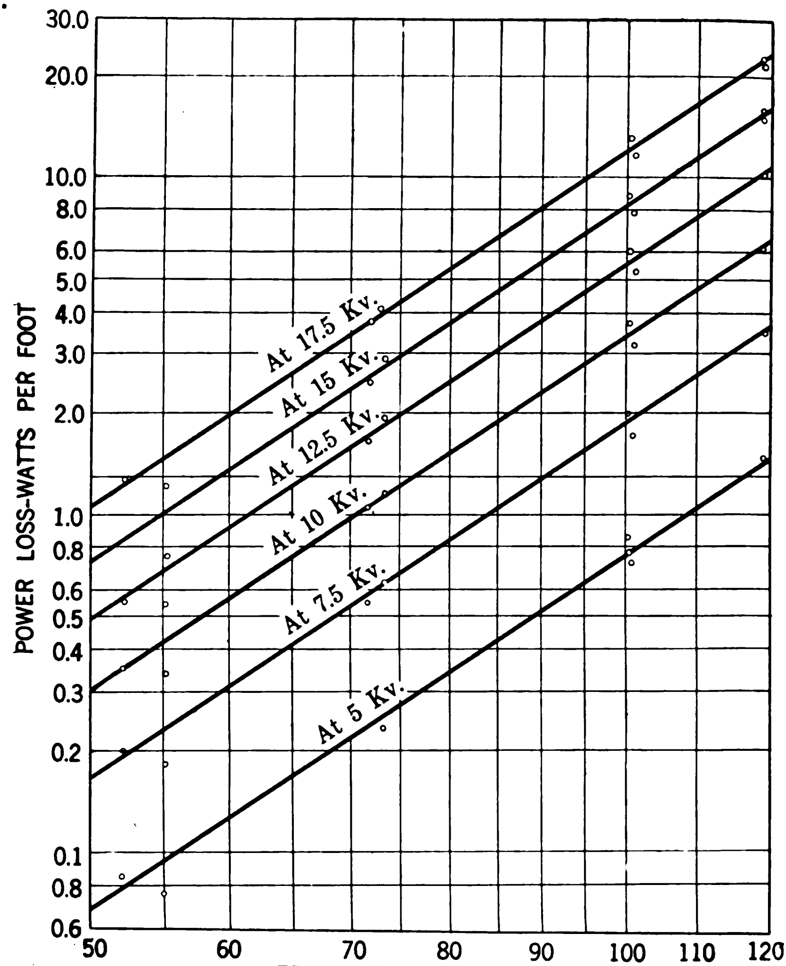


FIG. 7—POWER LOSS VS. TEMPERATURE AT VARIOUS TEMPERATURES—CABLE *B*—(LOGARITHMIC SCALE)

given in the tables were taken from these curves at fixed interval temperatures in order to make comparisons more convenient. It is obviously not possible in tests of this character to adjust the temperatures to exactly predetermined values.

Use of Logarithmic Scales. The general relations of the variables in experimental data are quickly comprehended when the

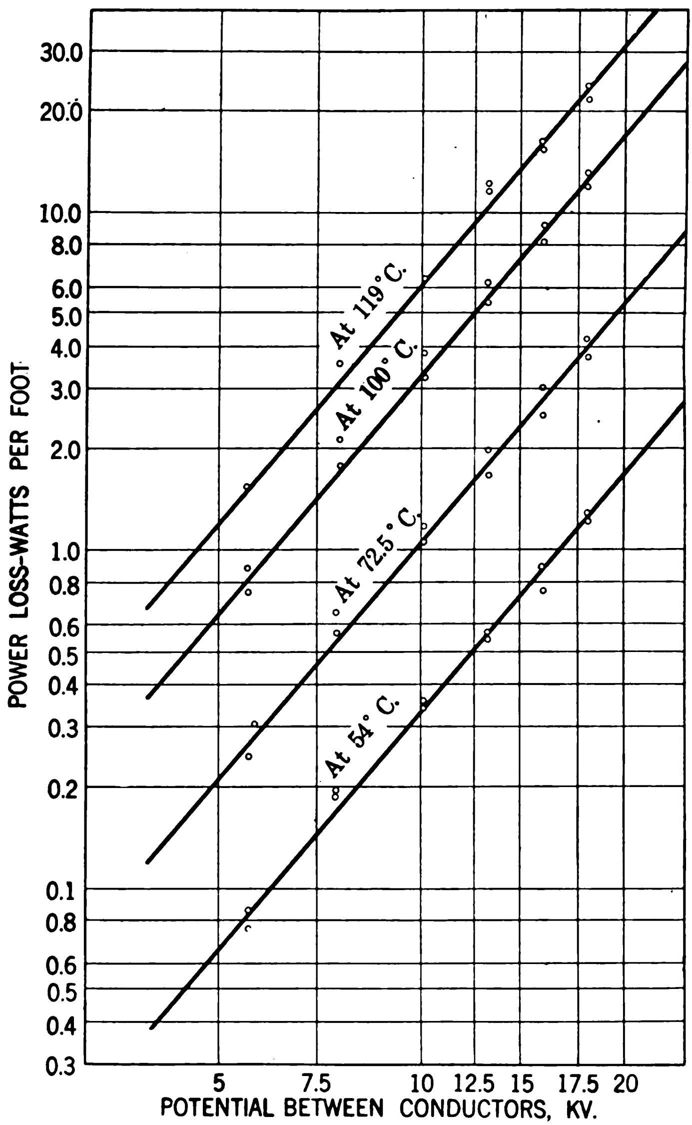


FIG. 8—POWER LOSS VS. VOLTAGE AT VARIOUS TEMPERATURES—CABLE *B*—(LOGARITHMIC SCALE)

data are presented in the shape of curves plotted in the usual way with rectangular co-ordinates and arithmetic scales. But when something more than simply the general relation of the

variables is desired, curves plotted with rectangular co-ordinates and logarithmic scales frequently have many advantages. For example, the curves plotted in Figs. 5, 6, 7 and 8 show:

(a) That no serious error was made because the points fall reasonably close to a form of definite curve which is easily drawn, namely a straight line.

(b) That the relation of two of the variables is independent of the third. Thus, in Figs. 5 and 7, the fact that the several lines are parallel shows that a given change in temperature will produce the same per cent change in power loss of the dielectric whether the potential applied to the cable is 5000 volts or 20,000 volts. Similarly, Figs. 6 and 8 show that a given change in

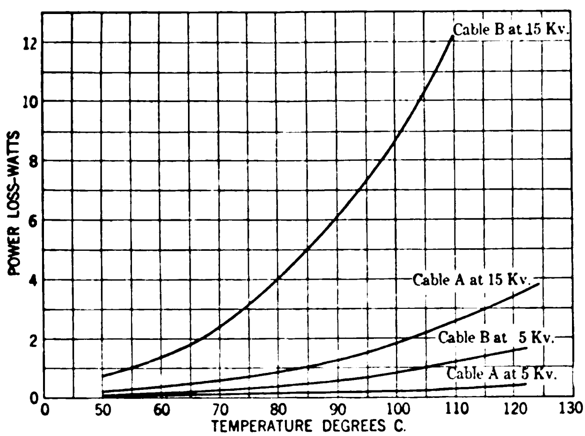


FIG. 9—AVERAGE WATTS VS. TEMPERATURE (ARITHMETICAL SCALE)

voltage will produce the same per cent change in loss whether the temperature is 50 deg. cent. or 100 deg. cent.

(c) That the curves being straight lines which make an angle with the axes, the loss varies with some constant power of the voltage and temperature respectively.

(d) That, the relation between the variables may be expressed by the equations:

$$W = k\ T^{n_t} \text{ and } W = k\ T^{n_e} \text{ where}$$

W = power loss of dielectric in watts, T = temperature in degrees C, E = potential in volts, n_t and n_e = exponents and k = constant.

The value of the exponents is readily computed from the relations

$$n_t = \frac{\log \dfrac{W_1}{W_2}}{\log \dfrac{T_1}{T_2}} \quad \text{and} \quad n_e = \frac{\log \dfrac{W_1}{W_2}}{\log \dfrac{E_1}{E_2}}$$

where W_1 and W_2 are the losses corresponding to temperatures T_1 and T_2, or to voltages E_1 and E_2.

The exponents for cables A and B referred to in the preceding tables and also for two other cables are given in the following

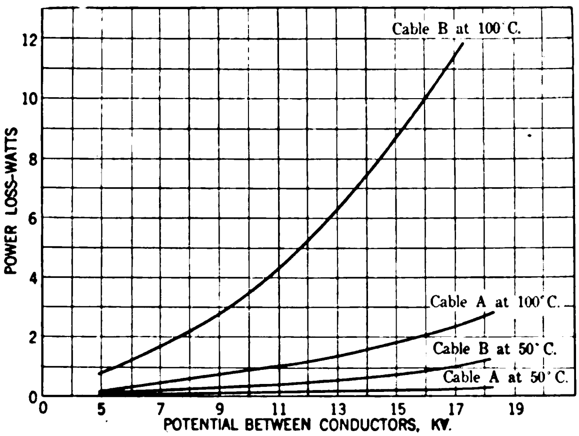


FIG. 10—AVERAGE WATTS VS. VOLTAGE (ARITHMETICAL SCALE)

tabulation. The power loss in the dielectric per foot at 80 deg. cent. and 15,000 volts is given for purposes of comparison.

Cable	n_t	n_e	W
A	3.36	2.07	0.85
B	3.54	2.34	3.85
C	3.77	2.01	1.76
D	4.26	2.16	2.62

n_t = exponent for temperature change, n_e = exponent for voltage change, W = power loss in the dielectric per foot in watts.

Three-Phase vs. Single-Phase Tests. Single-phase measurements were made on a number of specimens in addition to the

three-phase measurements. These single-phase measurements included the following, all measured at Y voltage:

(a) R_1, R_2, R_3 = power loss in the dielectric between each conductor and the other two conductors connected to lead sheath, that is referring to Fig. 12, $R_1 = W_1 + W_4 + W_5$, $R_2 = W_2 + W_4 + W_6$ and $R_3 = W_3 + W_5 + W_6$.

(b) R_4 = power loss in the dielectric between all three conductors connected together and the lead sheath, that is (Fig. 12) $R_4 = W_1 + W_2 + W_3$.

If it is assumed that the conditions with three-phase potential

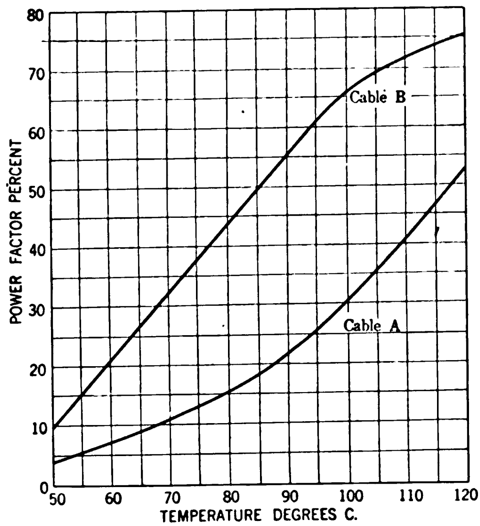


FIG. 11—AVERAGE POWER FACTOR VS. TEMPERATURE

are the same as in these single-phase tests, a value for three-phase loss can be computed from the relation

$$W \text{ (total watts)} = \frac{3\,(R_1 + R_2 + R_3) - R_4}{2}$$

The three-phase loss corresponding to single-phase conditions has been calculated on this basis for a number of cables and the ratio of the measured three-phase loss to computed loss is given in Table II.

These figures do not appear to settle definitely the question of the relation of measured and calculated losses. But if it is assumed that the variations or apparent inconsistencies have no

significance and that all of the figures for a given cable can be averaged, the results in the order of the cable designations are 1.015, 0.968, 1.010 and 0.967 respectively. It is questionable, however, if the variations are merely accidental because the data for the calculations were taken from straight line curves plotted on logarithmic paper. Furthermore, in some cases there seems to be a more or less definite change in the ratio with voltage especially in the case of cable *D*.

The most significant thing shown by these figures is that the measured value is very frequently considerably ***lower*** than the calculated value. If the figures are reliable, this indicates that the theory of a greater power loss in the dielectric between conductors with three-phase potential is not substantiated. In any case it is clear that this question should be investigated

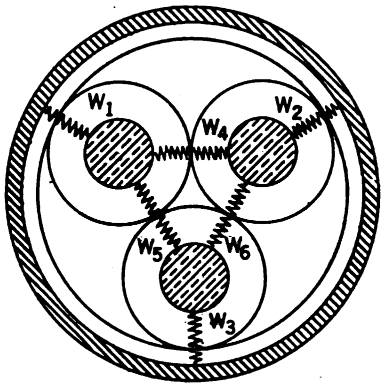


FIG. 12

further although it is probable that, for, all practical purposes, the power loss may be determined from two single-phase measurements without serious error.

Application of Data. The value of tests of this character may be largely relative because the results do not necessarily apply to operating conditions. In these tests the cable was at a uniform temperature throughout, while under operating conditions the temperature of the dielectric varies from a maximum at the conductor to a minimum at the lead sheath, so that the power loss per unit volume of insulation is higher near the conductor than it is next to the lead. However, Bang and Louis[6] found this gradient to be very small (lead temperature 86 deg., copper temperature 89 deg.) under conditions closely duplicating those in

6. loc. cit.

service. Of course if the temperature gradient is as small as these figures indicate, then it may be assumed without serious error that the entire cable is at the temperature of the lead and if this temperature can be measured, the total losses in the insulation can be computed if a laboratory test of a sample of the cable

TABLE II—RATIO OF MEASURED TO CALCULATED THREE-PHASE POWER LOSS IN DIELECTRIC

Potential between conductors, kilovolts	Temperature, deg. cent.			
	50	75	100	120
		Cable A		
5.0	0.79	....	1.03	....
7.5	1.07	....	1.02	....
10.0	0.91	....	1.03	....
12.5	1.16	....	1.02	....
15.0	1.11	....	0.96	....
17.5	1.11	....	0.98	....
		Cable B		
5.0	1.26	0.86	0.91	0.79
7.5	1.11	0.80	0.81	0.93
10.0	1.12	0.87	0.88	0.92
12.5	1.13	0.88	0.89	0.99
15.0	1.18	1.02	0.90	0.98
17.5	1.11	0.93	0.97	1.03
		Cable C		
5.0	....	1.05	1.06	0.96
7.5	0.96	0.94	1.03	1.02
10.0	1.03	1.00	1.09	0.95
12.5	0.91	0.93	1.04	0.95
15.0	1.07	1.10	1.11	1.00
17.5	....	....	....	....
		Cable D		
5.0	0.66	0.78	0.89	....
7.5	0.88	0.85	0.82	....
10.0	0.98	0.89	1.02	....
12.5	1.04	0.97	0.97	....
15.0	1.08	1.02	1.03	....
17.5	1.19	1.15	1.18	....

has been made. However, this question of what are the actual temperature conditions in practise is very important and in order to get data under conditions approximating working conditions, tests are now being made with a length of cable 20 feet long installed in a concrete conduit in the laboratory. The dielectric

power losses will be measured from time to time while the cable is carrying its rated current and rated voltage until constant thermal conditions have been reached. Incidentally, various temperatures will be measured including the copper by increase in resistance, and the lead by thermocouples. It is hoped that these data together with those already obtained for the same sample under other conditions will allow operation of the installed cable, which this sample represents, at maximum carrying capacity without danger of failures due to hot spots.

Conclusions

The following conclusions may be deduced from the preceding discussion:

(a) The power loss in the dielectric of a three-conductor cable under actual three-phase conditions can be readily measured in the laboratory with specimens ten feet long.

(b) No special apparatus is necessary for such measurements other than a reflecting high-sensitivity wattmeter.

(c) Apparently the power loss in the dielectric cannot in all cases be accurately calculated from data obtained in single-phase tests although it is highly probable that for all practical purposes, the discrepancy would not be serious. Further investigation is necessary, however, before final conclusions on this point can be stated.

(d) While the method of determining power losses in the dielectric directly by three-phase measurements involves more complication in preparation and slightly more time in the actual measurements, it has the important advantage that the results are conclusive and not subject to the uncertainty which pertains to results calculated from single-phase measurements.

These measurements have been successfully made up to potentials corresponding to 30,000 volts between conductors. At higher voltages it is probable that corona losses from the test circuits would soon begin to give trouble so that a guard circuit to take care of losses through the air in addition to those directly to ground would have to be provided.

The precision obtained in these measurements was probably not very high, perhaps not over five per cent but this was quite sufficient for the purpose in mind at the time, which was primarily to determine the approximate power loss in the dielectric of the samples at various temperatures. The other data obtained were incidental. It is believed, however, after considerable

experience with this method, that by taking particular care in the construction and arrangement of the apparatus, all of the important dielectric data of a cable can be obtained with a relatively high order of precision.

Much of the material in this paper was obtained in connection with a series of tests made for Mr. W. H. Cole, Supt. of Street Engineering, Edison Electric Illuminating Company of Boston, and the author wishes, in closing, to express his particular appreciation of Mr. Cole's courtesy in permitting the use of a portion of the information and data obtained in that investigation.

To be presented at the Sixth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 15, 1918.

THE CHARACTER OF THE THERMAL STORAGE DEMAND METER

BY P. M. LINCOLN

ABSTRACT OF PAPER

Following a detailed description of the principle and construction of the thermal storage demand meter the author shows wherein it always indicates what may be called "logarithmic average" rather than "arithmetic average" of power consumption, heretofore indicated by practically all demand meters. The inherent faults of the "arithmetic average" or "block interval" meter are described and examples given demonstrating that the thermal storage meter alone recognizes the true heating effect that fixes size of equipment and therefore cost that should be assessed against the customer.

THE ADVENT of the thermal storage wattmeter naturally raises a question concerning the character of the quantity that is measured by that device. The object of the following pages is to discuss this question and particularly to analyze the "logarithmic average"—the quantity measured by any thermal storage meter—and compare this quantity with the arithmetical average which is the quantity measured by practically all previously existing types of demand wattmeters.

Let us first consider the fundamental reasons for measuring maximum demand. Briefly stated, the incorporation of maximum demand in a rate for electric service is an attempt to assess upon the user of that service his proper share of the annual cost of the equipment necessary for giving the service. Let us assume a concrete case as an example. Assume, for instance, that the consumption of a given customer is 1000 kw-hr. per year. If this load is taken at a perfectly steady rate throughout the entire year it means a steady consumption of 114 watts continuously. The amount of equipment to supply the load as thus taken is fixed by this continuous load of 114 watts. But now let us assume that our customer insists on taking his entire year's supply in a single day. Instead of equipment to supply 114 watts, we must now provide equipment to supply 41.7

Manuscript of this paper was received on January 11, 1918; released for publication on January 18, 1918.

kilowatts; that is, the equipment must be 365 times as large as before. Let us go further and assume that our customer insists on having his entire year's supply in thirty minutes; this would mean an equipment able to deliver 2000 kw. for one-half hour. Obviously, the cost of the equipment for this condition would be enormously greater than that for the supply of 114 watts continuously, and it is only just that the customer that takes his entire year's supply in a day or an hour should pay more for his service than the one who distributes his demands more

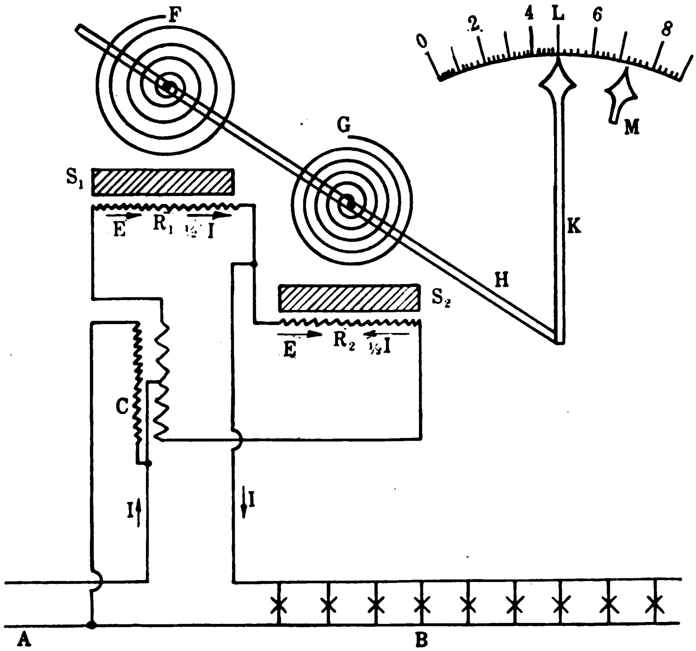


FIG. 1

evenly. Our illustration is, of course, exaggerated, but the exaggeration is one of degree and not one of kind. It is the object of the demand rate to recognize automatically this variation in the equipment necessary with variation in load factor and to assess this equipment cost against the customer. Also, it is the "maximum demand" and not the kilowatt hours of consumption that determines the amount of equipment that must be installed to carry a given customer's load. It is to determine this "maximum demand" that demand meters are used.

It may be well at this point to give a brief description of the thermal storage wattmeter as now being built.*

Referring to Fig. 1, A is a circuit feeding a load B. C is a small transformer incorporated within the meter with its primary across the circuit A. In series with the secondary of this transformer are two equal resistances R_1 and R_2. A current is, of course, set up on these resistances that is proportional to the voltage of the circuit A. The load current is also caused to circulate through these same resistances in the manner shown in Fig. 1, being taken into the middle of the secondary of the small transformer and being taken out at the connection between resistances R_1 and R_2. These two currents—one the secondary current, due to the presence of the voltage and the other due to the passage of the load current—are additive in one of these resistances and subtractive in the other, and the difference in the heating effect of the two resultant currents is proportional to the watts of the load B.

If we represent the current that passes through the resistance R_1 and R_2 due to the presence of the voltage by E, and the load current therein by I, the resultant current in one of these resistances is $E + I$, and in the other $E - I$. The losses are of course, proportional to the squares of these currents and the *differences* in these losses is proportional to the product $E\,I$. This holds true, independent of power factor and wave form, as shown in the paper above referred to.

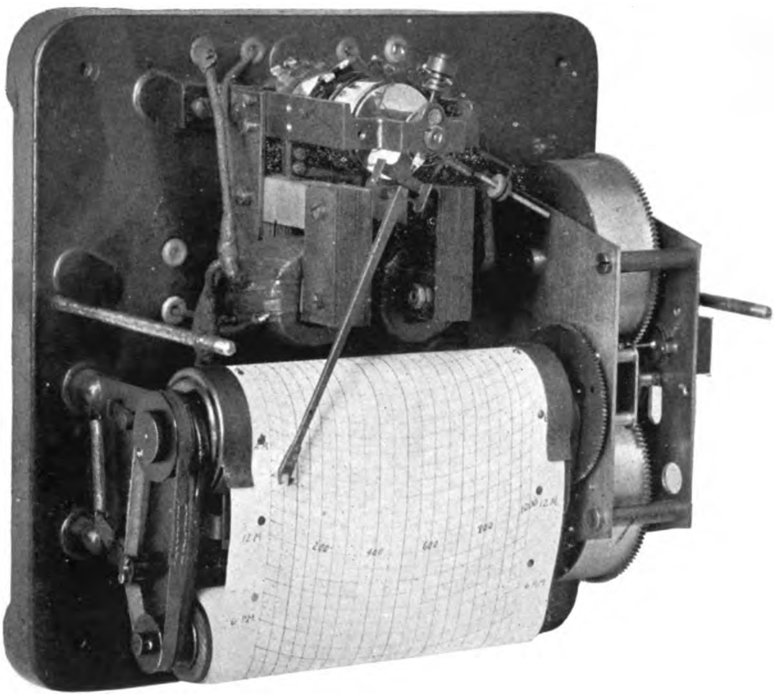
F and G represent two spiral springs made from bimetallic strip, attached rigidly to their casings at the outer ends and to a common shaft H at their inner ends. These bimetallic springs tend to coil up on an increase in temperature (due to the difference in temperature coefficient of the two metals of which they are composed), but, since the two springs are wound in opposite directions, no movement of the shaft H will take place unless there is a *difference* in temperature between F and G. The shaft H, therefore, will not turn with changes in atmospheric temperature or with any other condition that causes both springs to maintain the same temperature, but will respond only to the *difference* in temperature caused by the difference in the losses in resistances R_1 and R_2. S_1 and S_2 represent diagram-

*The complete theory of the thermal storage wattmeter is given in the author's paper read before the American Institute of Electrical Engineers, Oct. 8, 1915, entitled "Rates and Rate Making". (TRANSACTIONS A. I. E. E. Vol. 34, pages 2175 to 2214.)

matically the thermal storage of the cases in which the bimetallic springs F and G are enclosed. Due to this thermal storage, the wattmeter does not respond instantly to a change in load but always indicates the logarithmic average load over the time period immediately preceding the instant of observation, the length of this time period being determined in part by the amount of thermal storage in the cases, shown diagrammatically at S_1 and S_2. K is a pointer attached to shaft H and traveling over the scale L. M is a loose pointer which shows the highest excursion of pointer K since last reset.

Fig. 2 is made from a photograph of a graphic meter of the thermal storage type with the cover removed, showing the working parts. The two cylindrical cases each containing a coiled bimetallic spring may be observed at the top of the instrument. The thermal storage capacity of these cases is so designed that it requires thirty minutes for them to acquire 90 per cent of their final temperature on a steady application of load. The working parts of the indicating meter is a duplicate of that shown in Fig. 2, except for the omission of clock, paper rolls, etc.

A thermal storage meter thus constructed always indicates what may logically be called the "logarithmic average" of the power consumption during the particular time period immediately preceding the instant of observation. Quoting the language of the paper above referred to on this point, the indications of a thermal storage wattmeter "will not be due to the watts passing at that instant, as is the case with the indications of an indicating wattmeter of the usual type, but will be the resultant of all the wattage flow that has passed, each instant of past flow having a value influenced in respect to its time proximity by a logarithmic law. This resultant is not an average in the commonly accepted sense of that word. When we use the word average in its commonly accepted sense, we assume that each instant of time over which the average is taken has equal weight. In the resultant that is obtained by a heat storage meter, each instant of time has not an equal weight, but the influence of each instant decreases with its remoteness in point of time, and the degree by which the watts during any instant influences the total indication is proportional to e^{-Kt}, where e is the base of Napierian logarithms, K is an adjustable constant, and t is the time measured backward from the instant of observation. For want of another name, let us call the resultant thus obtained by means of thermal storage the 'logarithmic average.'" The



[LINCOLN]

FIG. 2

foregoing quotation indicates the nature of the quantity that is measured by the thermal storage demand meter. In a subsequent paragraph of this paper, a further quotation will be made from my previous paper showing how the "logarithmic average" of a given load may be calculated.

Heretofore, practically all demand meters have indicated in terms of the arithmetical average. This has followed from the fact that the basis of practically all previous demand meters has consisted of a standard watthour meter coupled with some timing device by means of which the integrated value of the load under measurement is obtained over a series of short time intervals. A further mechanism is provided so as to record the highest one of these successive blocks of energy. This type of meter is known as the "block interval" meter.

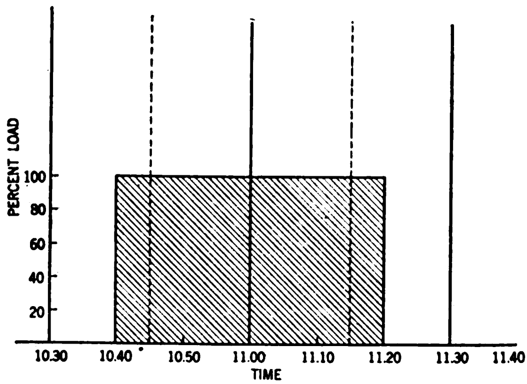


FIG. 3

One of its inherent faults is that it may split an isolated peak of load and therefore become indefinite in its indications. Reference to Fig. 3 will show the reason for this. Suppose we have an isolated block of load that comes on at say 10:40 a.m. and lasts until 11:30 a.m.—such a load for instance as would be involved in the pumping out of a small drydock. Suppose, further that we are using a "block interval" meter with a thirty minute time period to measure the maximum demand of this load. If the time intervals of this meter happened to begin and end on the even half hours—that is, if it integrated the load first from 10:00 to 10:30 and then from 10:30 to 11:30—it is evident that the maximum quantity indicated during any one period would be much less than if the meter periods began and ended on the even quarter hours. It is also evident by inspec-

tion that this indefiniteness of indication begins when the dura tion of the block of load is less than 60 minutes and that when its duration is less than 30 minutes, this "coefficient of indefiniteness"—if we may coin that term—becomes 50 per cent; that is, a load peak of less than thirty minutes duration may be entirely integrated within a single meter period or it may be divided equally between two adjacent periods depending upon the instant of time when these meter periods begin and end. There have been various suggestions of methods to overcome this fault but so far none of these suggestions has borne fruit.

A second and more serious fault of the "block interval" meter is that for isolated blocks of load it does not measure the

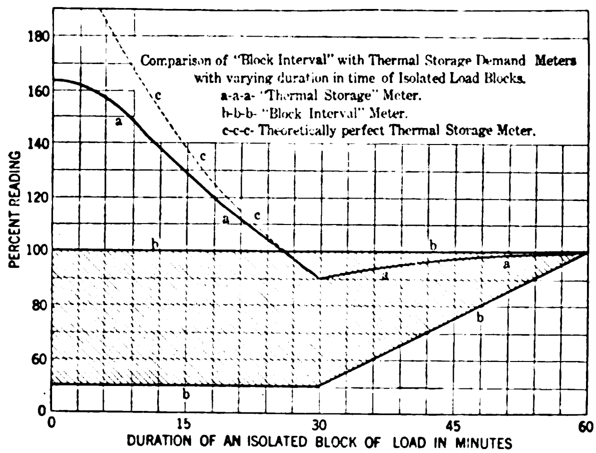


FIG. 4

true value of its heating effect on the equipment that serves the load and therefore does measure the true value of the duty on that equipment. This matter is further treated in subsequent paragraphs. There has been no suggestion of any method by which the "block interval" meter may overcome this fault and there seems to be no possibility of such a suggestion.

So long as the loads are steady over long periods of time, the arithmetical (block interval) and the logarithmic (thermal storage) averages are exactly the same. It is only when the duration in time of a block of load begins to come down to the time period of the meter that there is an appreciable difference between the two types. To assume a concrete case again, suppose that service is being sold on the basis of the maximum

demand over a 30-minute period. So long as the duration of an isolated block of load exceeds one hour (twice the meter period) the "block interval" and thermal storage meters will give the same results for all practical purposes. Theoretically, for periods of load duration greater than twice the meter period (sixty minutes in our concrete case) the difference between the two types is less than one per cent. For load duration less than 60 minutes, the comparison between the two types of meter is shown in Fig. 4.

The cross hatched area in Fig. 4 indicates what may be called the "area of indefiniteness" of a "block interval" meter of 30-minutes time period; for isolated blocks of load of less than 60 minutes duration, the indications of the "block interval" meter may fall anywhere within this area. On the other hand, the thermal storage meter is perfectly definite in its indication. Each time a given load of given time duration is applied to this type of meter, it gives the same indication.

However, this indication differs from that of the "block interval" meter and the comparison between the two types is given in curve *A A A* in Fig. 4. For a 60-minute block of load, there is a difference between the two types of only one per cent. As the block continues to decrease in time of duration, the thermal storage meter continues to decrease in indication compared to the "block interval" meter (assuming that the "block interval" meter is reading its maximum) until with a 30-minute block of load it reaches 90 per cent. As the time of load duration continues to decrease below 30 minutes, the indications of the thermal storage meter increase until with very short applications of load it indicates about 163 per cent of the maximum of the "block interval" meter and 326 per cent of its minimum.

There will be some one who will at first be constrained to comment adversely on the fact that the thermal storage meter reads higher than the "block interval" meter for all load durations less than about 26 minutes, and that when the load durations are very short, this discrepancy is so large. The action of the thermal storage meter in this respect is, however, entirely defensible. Referring, for instance, to the same concrete example we used above, suppose our customer with a yearly consumption of 1000 kw-hr. insists on taking his entire year's supply in one minute. He would obviously use energy during this one minute at the rate of 60,000 kw. Electrical equipment can, of course, be grossly overloaded for so short a time as one minute, but even

with the greatest overload imaginable, the amount of equipment to carry 60,000 kw. for one minute is more than that to carry 2000 kw. for 30 minutes. The "block interval" meter would recognize no difference whatever between these two conditions, since the arithmetical average of the two loads when taken over a 30-minute period is exactly the same. The thermal storage meter, however, discriminates automatically against the short-time high-peak load and gives a result which in any event follows the same kind of a law as does the heating of the equipment that

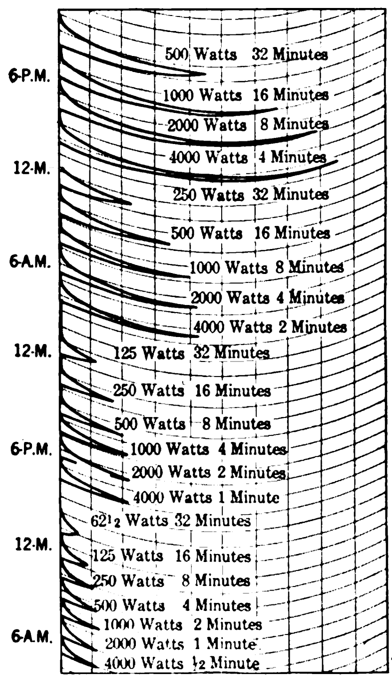


FIG. 5

furnishes the power. In short, both the "block interval" and the thermal storage meters recognize the effect of load factor so long as the duration of the block of load is equal to or greater than the meter period. However, when the load duration is less than the meter period, the "block interval" meter recognizes no difference while the thermal storage meter continues to recognize the heating effect of a given block of load entirely independent of its duration in time. It is the *heating effect* that fixes the size of the equipment, and, therefore, the cost

that should be assessed against the customer. It follows, therefore, that the indications of the thermal storage meter are more logical for rate making purposes than are those of the arithmetical average or "block interval" meter.

In this connection, the results of tests shown in Figs. 5, 6, 7, 8 and 9 will be of interest. These show the results of a number of test runs made with a graphic meter of the thermal storage type. These tests were made on the instrument shown in Fig. 2. The time period was 30 minutes; that is, the application of a steady load would bring the meter indication to 90 per cent of final at the end of 30 minutes, 99 per cent at the end of 60 minutes, 99.9 per cent at the end of 90 minutes, etc. The paper speed was one-quarter inch per hour and the full scale was 1000 watts. Fig. 5 shows the result of four series of tests. In the first series shown at the right hand bottom of Fig. 5, 2000 watt-minutes were applied to the meter, each test of the series starting at zero. In the first test of the first series the whole 2000 watt-minutes were put in in one-half minute; that is, power was applied at the rate of 4000 watts (four times normal load) for one-half minute. After the meter had had time to return to zero, the second test of the series was applied, viz., 2000 watts for one minute. The third block was 1000 watts for two minutes; then follow 500 watts for four minutes, 250 watts for eight minutes, 125 watts for 16 minutes and 62.5 watts for 32 minutes. If these same tests had been applied to a "block interval" meter they would all have given the same results (barring the "indefiniteness" mentioned in a preceding paragraph) if measured on a 30-minute meter except, of course, the last test of the series, which would have been lower than the others in the ratio of 30 to 32. I think there are very few who will contend that the customer who insists on taking his entire half hour's requirements in a half minute should not pay a larger demand rate than the one who spreads it out evenly throughout the half hour.

The second series of tests, shown in Fig. 5, is the same as the first except that the amount of power is doubled, 4000 watt-minutes being applied instead of 2000. No tests were made that involved applying load at a rate greater than four times normal. Similarly, in the third and fourth series of tests, 8000 and 16,000 watt-minutes were applied respectively, with the results shown. Comparing the four series of tests with each other, it will be seen that doubling the watts for a given time period doubles the meter indications, as, of course, might have been anticipated.

Comparing now the individual tests of a given series and comparing these results with those deduced from purely theoretical considerations, we find that the quantity indicated by the actual

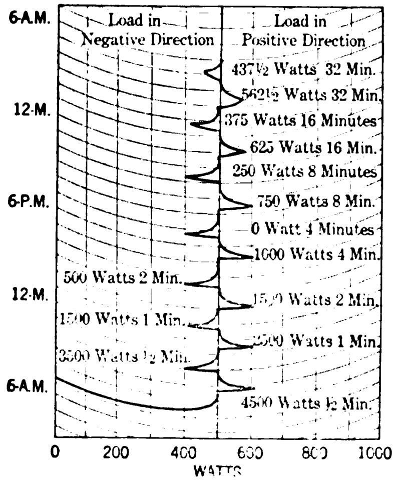


FIG. 6

meter when subjected to isolated short time blocks of load is not as great as the true logarithmic average. Referring to Fig. 4, for instance, the curve *AAA* and the area *BBB* compare the

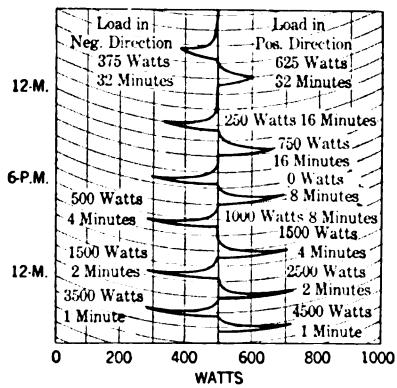


FIG. 7

actual thermal meter with the equivalent "block interval" meter. If the thermal meter had followed a true logarithmic law, the comparison would have been shown by the dotted curve *CCC*

instead of the solid curve *AAA*. The reason for this and a discussion thereof will be set forth in a later paragraph of this paper.

Figs. 6, 7 and 8 are identical with Fig. 5 insofar as the value of the load fluctuation is concerned, but the fluctuation is made with the meter starting from and returning to the *half* load point instead of the zero load point. In Fig. 6, for instance, there is shown a series of tests that are taken with the application of the following schedule. The meter was operated at 500 watts for a long enough period for the pen to take up the 500 watt position; then, 4500 watts was applied in a positive direction for one-half minute and the load was returned there-

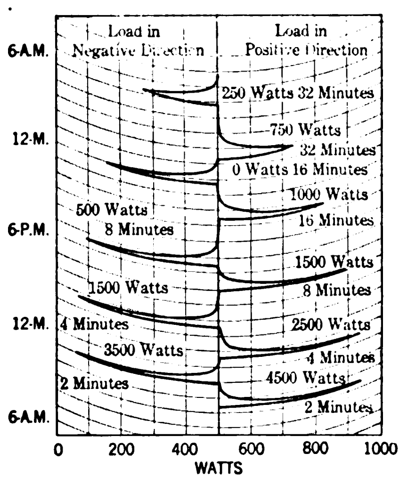


FIG. 8

upon to this 500-watt point. After the return of the pen to the steady 500-watt position, 3500 watts was applied to the meter in a negative direction for one-half minute, the load then being returned to the 500 watt point. This caused the pen to travel in a negative direction by the same amount as the first application caused it to travel in the positive direction. Also, it will be noted that the travel of the pen in both these tests is the same as in the first test of the first series in Fig. 5. The remainder of the tests in Fig. 6 are according to the following schedule, it being understood that after the application of the scheduled load, the load was in each case returned to the 500-watt point:

2500	watts	in	the	positive	direction	for	1	minute.
1500	"	"	"	negative	"	"	1	"
1500	"	"	"	positive	"	"	2	minutes
500	"	"	"	negative	"	"	2	"
1000	"	"	"	positive	"	"	4	"
0	"	"	"			"	4	"
750	"	"	"	positive	"	"	8	"
250	"	"	"	"	"	"	8	"
625	"	"	"	"	"	"	16	"
375	"	"	"	"	"	"	16	"
562.5	"	"	"	"	"	"	32	"
437.5	"	"	"	"	"	"	32	"

In other words, this schedule is a repetition of that shown in Fig. 5, except that it goes both ways from the 500-watt point instead of only one way from the zero point. A comparison of the various readings indicates that a given departure in load from the 500-watt point gives exactly the same result as the same degree of departure from the zero point—a result that might have been expected.

Figs. 7 and 8 show the same thing as Fig. 6 except that the loads are respectively twice and four times those in Fig. 6. These results may be compared directly with those in Fig. 5. Fig. 9 shows the result of a load schedule exactly similar to Fig. 5 except that the point of departure is made the full-load or 1000-watt point instead of the zero point as in Fig. 5, or the 500-watt point as in Figs. 6, 7 and 8. Figs. 5, 6, 7, 8 and 9 indicate that a given departure for a given time from the previous steady condition always gives the same result independent of where that previous steady condition has maintained the pen.

In the foregoing tests are given the results of applying isolated blocks of load to the thermal storage meter. The question now naturally arises, suppose the blocks of load are not isolated, but follow each other before the meter has had time to return to zero. The series of tests shown in Figs. 10, 11, 12, 13 and 14 were undertaken to answer this question. Fig. 10, for instance, shows three series of tests. In the first series, (shown at the right hand side of Fig. 10) 1000 watts were put on the meter and kept on for one minute; the load was then thrown completely off for one minute, that is, the time cycle was two minutes long. Both the load and the time of application were then accurately kept on a repetition of this load schedule for about one and a half hours. It will be noted that the meter pen came to a steady value of 500 watts just as if a steady load of 500 watts were

applied instead of a full load and zero load during alternate minutes. The second series of tests shown in Fig. 10 is exactly similar to the first, except in point of time of power on and power off, being a two-minute interval instead of one minute; that is, the time cycle was four minutes long. In the third series, the time cycle of load on and load off is ten minutes long, five minutes on and five off. Referring now to Fig. 11, which is a continuation of Fig. 10, this shows three similar series of tests, the difference being that the time cycles are 20

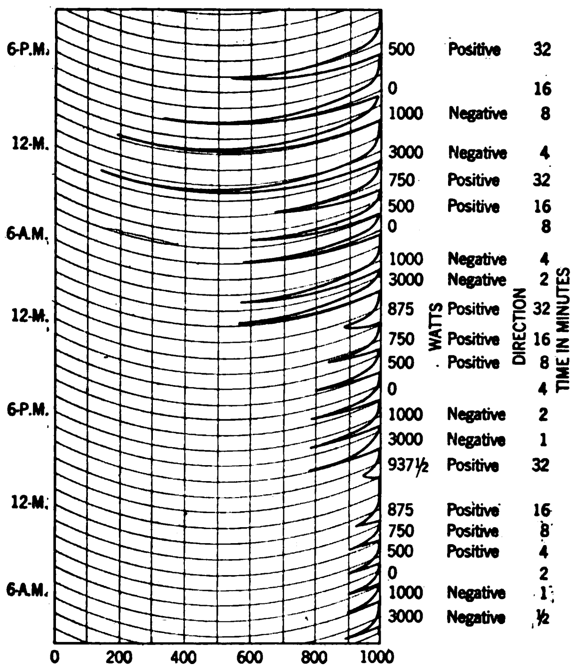


FIG. 9

minutes, 30 minutes and 60 minutes, respectively. In each of these power schedules, the average use of power is of course, at the rate of 500 watts. With the two-minute cycle the successive blocks of power blend into each other so that the result is the same as if 500 watts were applied continuously. When time of the cycle is increased to four minutes, the pen responds slightly to successive blocks of load application; the total travel of the pen being perhaps two per cent of the total scale. When the time of the cycle becomes ten minutes, this travel increases to

about ten per cent of total scale. With a 20-minute cycle, this travel becomes about 25 per cent; with a 30 minute cycle about 45 per cent and with a sixty minute cycle, 80 per cent. If we compare the thermal storage meter with the "block interval" meter for these various load conditions, we will note the rather curious fact that for certain time intervals, the "block interval" meter has an "area of indefiniteness," while for others it has not. Figs. 12, 13 and 14 show a number of series of tests on power

TABLE I.

Duration of cycle minutes	Per cent of time of power on	Meter indications.		
		Logarithmic	Block interval	
			Maximum	Minimum
2	0.25	250	250	250
2	0.50	500	500	500
2	0.75	770	750	750
4	0.25	260	267	250
4	0.50	510	533	500
4	0.75	775	767	750
10	0.25	285	250	250
10	0.50	550	500	500
10	0.75	800	750	750
20	0.25	360	333	250
20	0.50	640	667	500
20	0.75	855	833	750
30	0.25	425	250	250
30	0.50	725	500	500
30	0.75	890	750	750
60	0.25	640	500	250
60	0.50	900	1000	500
60	0.75	980	1000	750

cycles of the same length as in Figs. 10 and 11—viz., the cycles are of two minutes, four minutes, 10 minutes, 20 minutes, 30 minutes and 60 minutes. However, in Figs. 12, 13 and 14, the power is kept on during one-fourth and three-fourths of the time instead of one-half of the time as in Figs. 10 and 11. The resulting pen traces are highly interesting and instructive. Tabulating all of these results we arrive at the comparison between the two types given in Table I.

The two minute, ten minute and thirty minute cycles all give an arithmetical average of 250, 500 or 750 watts as the case may be, independent of the point in the cycle where the meter period begins. The other time intervals vary over the limits assigned in Table I, depending on what point in the power cycle the meter period begins.

It is evident from an inspection of Figs. 10, 11, 12, 13 and 14 as well as the foregoing table that the values indicated by the thermal storage meter increase in a definite, logical and consistent manner as the time period between peaks is increased

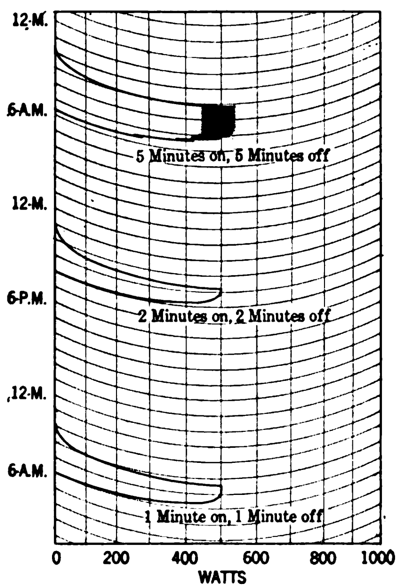


Fig. 10

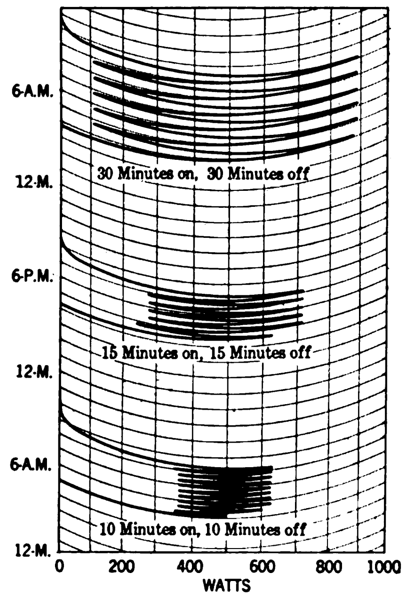


Fig. 11

while the "block interval" meter gives results that are indefinite, illogical and inconsistent under the same conditions. In other words, the thermal storage meter recognizes the maximum heating effect of a given load application of any character, while the "block interval" meter does not.

It may be of interest at this point to make a brief analysis of the action of the thermal demand meter and show the reasons for its departure from indicating a true logarithmic average for isolated short time loads as was referred to in a previous paragraph. Fig. 15 is a reproduction of Fig. 6 taken from the au-

thor's A. I. E. E. paper of October 8, 1915, and referred to in a previous paragraph. This shows how the "logarithmic average" of a given load may be calculated from purely theoretical considerations. Quoting from that paper, page 2195: "Suppose we have a load constantly varying with time as indicated by the broken line *C H D E I K F M*. If we apply a thermal storage meter to this load of such characteristics that it requires an hour for it to attain 90 per cent of its final indication, the cooling (or heating) curve of that meter will follow the law indicated by curve *A*. The quantity that will be indicated by such a thermal storage meter at any given instant (for instance, at 12 o'clock in Fig. 6), will be proportional to the cross-hatched

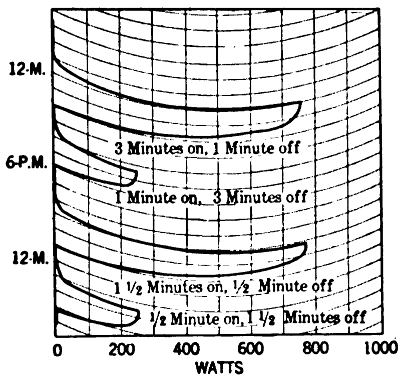


FIG. 12

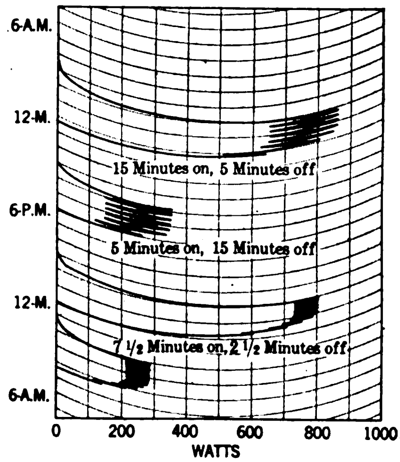


FIG. 13

area under the broken line *C′ H′ D′ E′ I′ K′ F′ M′*. The value of the ordinates of this cross-hatched area at any instant are proportional to the value of the power ordinate at that instant reduced by the ratio of the ordinate of curve *A* at that instant to the maximum ordinate *O G* of curve *A*. If we can just imagine this curve *A* as continually sliding along the power curve, the quantity which it measures will always be proportional to an area that is secured at each instant, just as Fig. 6 shows it at the instant of 12 o'clock.

"If our meter is a ten-minute meter instead of one-hour meter—that is, if it takes only ten minutes to cool down or heat up to within 10 per cent of its final value—the quantity that will be measured will be proportional to the cross-hatched

area under the broken line $K'' F'' M''$. In this case, the ordinates of this area are reduced in accordance with the logarithmic curve B instead of A; the curve B comes down to 10 per cent of its initial value in ten minutes instead of one hour as is the case of A."

The above shows the method of calculating the indications of a theoretically perfect thermal storage meter. For short time applications of load, however, the actual meter is not theoretically perfect. The principal cause for this departure is the fact that diffusion of heat throughtout the mass of a meter

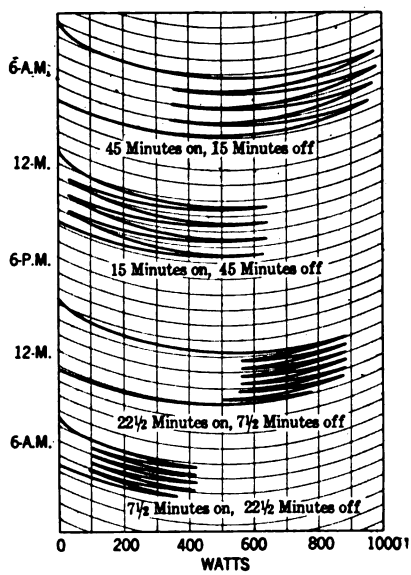


FIG. 14

element is not instantaneous. Consider, for instance, the application of a one-minute load to such a meter. Test shows that it takes nearly five minutes after the load is thrown off before the pointer reaches its maximum position. The application of this isolated block of load heats one meter element and cools the other from the previous steady condition. This wave of heat change, of course, originates in the resistance, but to effect the meter must pass to the spiral bimetallic springs. That is, the heat must first pass from the resistances to the casings enclosing the springs, then the air inside the casings is heated and this, in turn, heats the bimetallic springs. The heat must get

from the resistances to the bimetallic springs before the meter will respond. This process takes time. During this time some heat that has been put into the resistance escapes from the casing partly by radiation and convection and partly by conduction back through the lead wires. This action leads to no departure from theoretical when the load is steady but only when the load is an isolated block. The amount of this departure can readily be found from the results of the tests shown in Figs. 5, 6, 7, 8 and 9 and the comparison of the actual meter with the theoretically perfect meter is shown by comparing the solid and dotted lines in Fig. 4. This comparison is also shown directly in Fig. 16. It might be noted that such departure as

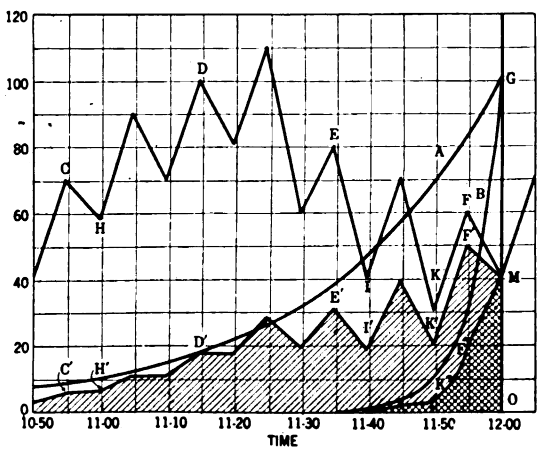


Fig. 15

there is from the theoretically perfect meter causes the actual meter to read lower than the theoretical. This is the "safe" position. If any device used in determining a customer's bill, favors the company supplying the service, it can be successfully attacked by the customer. If the contrary is true, it cannot. Hence, the departure noted is on the "safe" direction.

An objection has been raised to the thermal storage meter in that it reads higher on an increasing load than it does on a decreasing load, the kilowatt hours and the time of application being the same in both cases. The tests shown in Fig. 17 were undertaken to find the value of this discrepancy. In this figure, the first test (beginning at the right hand side) was made by applying 10 per cent load during the first minute, 20 per cent

during the second minute, 30 per cent during the third, etc., until ten periods of one minute each had been applied, the last one minute period being 100 per cent load. In the second test, exactly

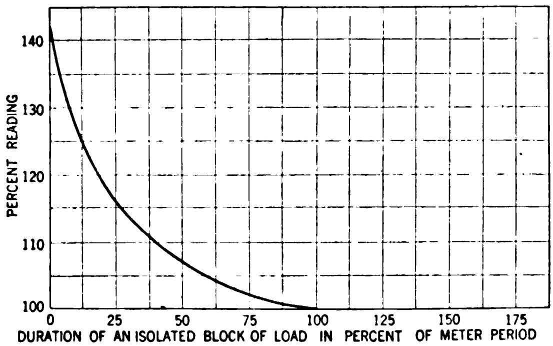


FIG. 16—THEORETICALLY PERFECT THERMAL METER COMPARED TO ACTUAL PERFORMANCE

the same load schedule was applied, except that the time of each application was made for two minutes instead of one. In the third test, this time period was increased to five minutes. In

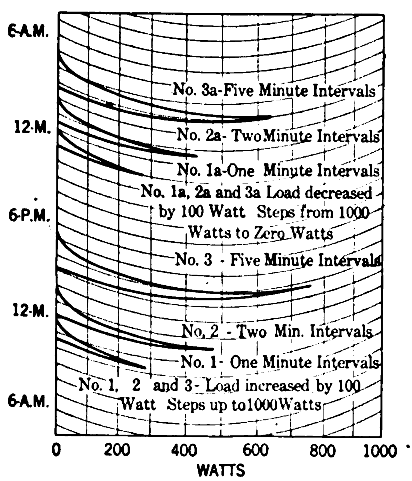


FIG. 17

the next series of tests, the load was made to decrease with time instead of increase; during the first time interval, 100 per cent load was applied, followed during the next interval by 90 per cent load, then 80 per cent, etc., until during the tenth interval 10

per cent load was applied. The time intervals were one minute, two minutes and five minutes as in the first series. The comparison of the actual thermal meter, the theoretically perfect logarithmic average meter and the arithmetical average meter for these various load applications is given in the following table. (Percentage is variation from perfect logarithmic meter.)

Time interval. Minutes	Nature of load	Actual meter	Theoretically perfect meter	Block interval meter	
				Maximum	Minimum
1	Increasing	295 (10.2%)	328	187 (43%)	93 (71.5%)
1	Decreasing	275 (1.8%)	280	187 (33.3%)	93 (66.7%)
2	Increasing	480 (9.4%)	529	373 (29 5%)	187 (64 7%)
2	Decreasing	425 (0%)	425	373 (12.3%)	187 (56%)
5	Increasing	760 (4%)	792	750 (5.2%)	450 (43.2%)
5	Decreasing	630 (0.2%)	631	750 (9.6%)	450 (28.8%)

The reason for the difference in indication between increasing and decreasing loads is readily seen by reference to Figs. 18, 19 and 20. In Fig. 18 the method of analysis shown in Fig. 15 is applied to a load increasing by 10 per cent steps. The reading of a theoretically perfect meter on such a load would be proportional to the cross-hatched area in this figure. Fig. 19 shows the same method of analysis applied to a decreasing load. The cross-hatched area in this figure is obviously less than that in Fig. 18. However, the instant chosen in Fig. 19 is not the instant of maximum indication. The instant of maximum indication with a decreasing load occurs before the entire block of load has passed through the meter. The instant shown in Fig. 20 gives a considerably larger cross-hatched area than that in Fig. 19. In other words, with a decreasing load, the maximum indication arrives before the whole load has been put in. Or, to put it in another way, with an increasing load, each increment of load finds the meter already heated by the preceding load and the maximum load is applied to the hottest meter element. With a decreasing load, the maximum load is applied to the coldest meter condition and the maximum temperature arrived at is not as great as with an increasing load. This action is entirely defensible since exactly the same action takes place in the equipment that serves the load. An increasing load heats up transformers, cables, generators, etc., more than does a

decreasing load, although the kilowatt-hours and the time of application are exactly the same in each case.

The question may properly be raised as to the proper time period to use in the measurement of maximum demand. At present, the practise of various public service companies varies in this respect over a very large range. One minute is the minimum time duration for maximum demand measurement that the author is aware of and one hour is the maximum. Between

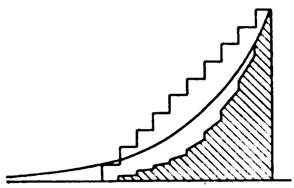


FIG. 18

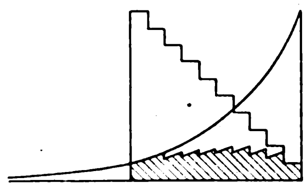


FIG. 19

these limits a large number of time periods have been proposed and used. So long as it is recognized that equipment cost is the element that dictates the maximum demand portion of a customer's bill, the use of time periods of less than about thirty minutes cannot be justified, since no part of a normal equipment for supplying electric service to a customer has heat storage characteristics that will cause it to arrive at 90per cent of its final temperature in less than thirty minutes and many of the items of such

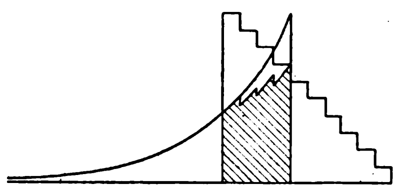


FIG. 20

an equipment have a much longer time period. In many cases, short-time periods for maximum demand have been adopted for the purpose of penalizing the customer with a high short-time peak. The thermal demand meter does this automatically and, therefore, there is not the same reason for using short periods when measuring demands with a thermal meter that there is when using the "block interval" meter. For steady loads, it does not matter whether the demand is on a one minute or a

one hour basis, the result is the same. The average generator, transformer or cable has heat storage characteristics that usually require a time considerably in excess of 30 minutes for them to arrive at 90 per cent of their final temperature when a steady load is applied. A 30-minute meter, therefore, is about the minimum time period for maximum demand that can be justified on the score of assessing equipment costs against the customer and the tendency of the future will undoubtedly be toward longer time periods. The 30-minute thermal demand wattmeter is the first time period to be developed but other time periods will be brought out as occasion requires.

Summary

1. The cost of electric service is dependent in part upon the cost of the equipment necessary to provide that service.

2. The cost of the necessary equipment to a given customer depends upon his maximum demand and not on his kilowatt-hours of consumption.

3. The thermal storage demand meter gives a perfectly definite indication independent of the character of the load applied while the "block interval" demand meter becomes highly indefinite on short-time peak-load applications.

4. For short-time peak-load applications the thermal storage demand meter follows a law of the same nature as the heating effect of the load application upon the service equipment, while the "block interval" meter does not.

5. For steady loads the thermal storage and "block interval" demand meters give identical results.

6. The thermal storage demand meter gives a much higher indication for a very short-time peak-load application than does the "block interval" demand meter, thereby making unnecessary the adoption of short demand periods designed to penalize such high peak loads.

To be presented at the Sixth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 16, 1918.

COMMUTATION IN ALTERNATING-CURRENT MACHINERY

BY MARIUS C. A. LATOUR

ABSTRACT OF PAPER

As is now well known, the inductive reactive effect of a commuted winding in a revolving magnetic field decreases directly with the increase in speed from standstill to synchronism, when its value becomes zero. As first pointed out by the author some years ago, it becomes negative at speeds above synchronism, under which condition the rotor of a motor operates as a capacity.

The author introduces into the discussion of the commutating characteristics of alternating-current commutating motors, his theory that perfect commutation in a continuous-current motor depends substantially on the production of a mean resultant neutral field in the region where commutation is taking place, and shows that the production of a perfect revolving field in a polyphase commutator motor assists in insuring perfect commutation at exact synchronism.

In a single-phase commutator motor a "polyphase" revolving field can be produced at synchronism by utilizing supplementary brushes, short-circuited upon themselves, displaced by 90 electrical space degrees from the main single-phase brushes on the commutator.

As in the case of polyphase motors, the problem of securing perfect commutation at synchronism becomes that of producing a perfect rotating field. It is shown by the author that the use of fractional-pitch windings on the rotor and a sinusoidal distribution of conductors on the stator is of much assistance in this connection.

In a motor built in accordance with the principles set forth, the commutator difficulties are not serious, the overload range is in excess of that of an induction motor, and the machine can act as a condenser on the system.

THE writer has already had the honor of presenting two communications on the use of commutators with alternating currents before the American engineering public, the first being in June, 1903, in co-operation with Mr. A. S. Garfield (see *The Compounding of Self-Excited Alternating Current Generators, for Variation in Load-Factor*, in A. I. E. E. TRANSACTIONS, Vol. XXI, pages 569-577, and discussion, pages 583-585); the other being a paper presented at the St. Louis Congress, 1904, ("*Alternating Current Machines with Gramme Commutators*," published in Transactions of the International Electrical Congress of St. Louis, 1904, Vol. III, pages 149-154).

The purpose of the present paper is to enter more deeply into the theoretical considerations which were outlined by the writer in his earlier publications, and which have since been verified by practical experience. A distinction will be made between the use of commutators for polyphase and for single-phase alternating currents.

I—Commutation in Polyphase Machinery

Let us consider a direct-current bipolar armature, *A*, Fig. 1, placed in a uniform air gap inside the laminated stator, *B*, with regularly spaced slots and receiving sinusoidal currents of p phases, of frequency equal to $\omega/2\pi$ through p brushes located at points situated $2\pi/p$ in angular distance from each other.

Fig. 1 shows diagrammatically a smooth core armature, on which four brushes, *a*, *b*, *c*, *d*, make contacts through which two-phase (more properly four-phase) currents are supplied. The brushes, *a*, *c*, receive a current $I \sin \omega t$, and the brushes *b*, *d*, receive a current $I \cos \omega t$. Suppose the armature to be at rest and let $L\omega$ be its inductance per phase. If the armature is made to turn at the angular velocity ω_1, measured in the direction of the rotating field developed by the polyphase currents, it will be found that the inductance of the armature becomes $L(\omega - \omega_1)$; consequently, it will vanish at synchronism and, above synchronism, the arrangement will operate as a capacity (condenser).

When this property was first made known by the writer, in his patents, in 1900-1901, its correctness was questioned by several prominent electricians. Among these, M. Maurice Leblanc devoted a long article (see *Eclairage Electrique*, October 26th, 1901, pages 113 *et seq*) to the refutation of the writer's conclusions. Many electricians have, since then, accepted as satisfactory the theory which introduces the relative velocity $(\omega - \omega_1)$ of the revolving field developed by the armature with respect to the armature itself. Mr. Leblanc, however, maintained, in his article, that since the current, *i*, in each turn of the armature winding, preserved its variable character, no matter what the velocity ω_1 might be, and consequently at any instant t was subject to the same rate of variation, $\frac{di}{dt}$, the e. m. f. of self-induction between the brushes should persist at all speeds.

As was shown by the writer, in a detailed article, published in November, 1901, (see *Eclairage Electrique*, 1901, pages 294

et seq), it is quite true that the e. m. f. of self-induction of the sections included in the circuit between the brushes persists independently of the velocity ω_1; but, in consequence of the phenomenon of commutation, there appears between the brushes an e. m. f. of opposite sign which is proportional to the velocity ω_1, and which is due to the mutual induction between the sections which are short-circuited and those which are in the circuit.

In this connection, let us consider Fig. 1. Let M be the coefficient of mutual induction between the sections which are short-circuited by the brushes, b, d, and the sections that remain in circuit between the brushes a, c. Let n be the number of sections of the armature. With brushes covering the width of a commutator segment, the duration of commutation for the sec-

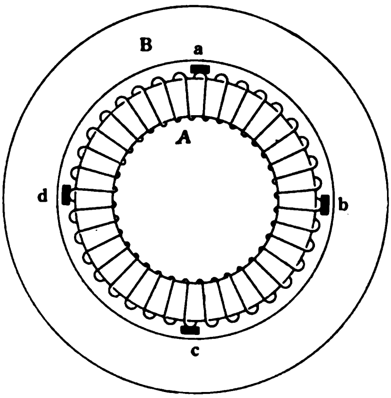


FIG. 1

tions of winding passing under the brushes b, d, at the velocity ω_1, will be $T = \dfrac{2\pi}{\omega_1 n}$. The e. m. f. E_M developed by mutual induction between the short-circuited sections passing under the brushes b, d, (where the reversal of a current $\frac{1}{2}\ I \cos \omega t$ is taking place during the time T) and the sections which are in circuit between the brushes a, c, (through which the current $I \sin \omega t$ passes)will be $\dfrac{M}{T}\ I \cos \omega t = \dfrac{Mn}{2\pi}\ \omega_1\ I \cos \omega t$.

We first ascertain that E_M is opposed in polarity to the e. m. f. of self-induction $E_L{}' = L\ \omega\ I \cos \omega t$, due to the self-induction of the armature; and we then can show that, in the case where

each section of the armature is supposed to produce a sinusoidal flux at the armature periphery, we will have $\frac{Mn}{2\pi} = L$ and consequently $E_L - E_M = L(\omega - \omega_1)$.

It is to be noted that the same expression may be obtained for the e. m. f. (E_M) by supposing it to be produced by the rotation of the armature by its own field produced by the current sent through brushes a, c; but this explanation of the appearance of the e. m. f. E_M, though it may always be correct from the mathematical point of view, is not quite so near the physical reality, since, as a matter of fact, the field of the armature itself must follow the armature in its rotation.

The fact that the armature in the arrangement shown in Fig. 1 can operate as a capacity (namely when ω_1 *exceeds* ω) was of particular interest to Mr. Leblanc, who, about that time (in 1902) was endeavoring to find a simple electrical system susceptible of being used in place of the condensers which he was placing in the rotors of induction motors, for the purpose of improving their power-factor. He had even, for that purpose, devised the combination of two single-phase machines provided with commutators. In Mr. Leblanc's arrangement an induction motor C was connected in cascade with a simple armature A, such as that shown in Fig. 1, running at a speed greatly in excess of synchronism with respect to the frequency of the rotor currents of machine C (see Fig. 2). This was an immediate indication of the value of the writer's article of November 23rd, 1901, as Mr. Leblanc himself has since expressly acknowledged, (see *La Lumiére Electrique*, July 12th, 1913, page 60, and the *Electricien*, July 25th, 1913, page 658).*

The Swiss firm of Brown-Boveri, utilizing the methods patented by M. Leblanc for improving the power-factor of induction motors, has put on the market, in the last few years, under the name of phase-compensator, armatures with commutators rotating above synchronous speed. Fig. 3, made from a photograph, shows one of these arrangements, designed for a

*The writer had formally proposed that combination to Mr. Leblanc in a letter addressed to *Industrie Electrique* (in 1902) which was not published; but the writer, in any case, considers that M. Leblanc should be credited with the idea of placing condensers or any dynamic apparatus equivalent to them in the rotor of induction motors for the purpose of improving their power-factor. It is by mistake that the arrangement shown in Fig. 2 was, during a certain time, attributed to Mr. Scherbius.

500 h.p. 50-volt motor, operated by a motor of 0.8 h.p., running at 1000 rev. per min. This outfit relieves the supply mains of the necessity of furnishing 180 kv-a. of reactive current.

With respect to the introduction of a commutator to bring the power-factor of an alternating current system up to unity, the question has been asked whether it would not be possible to raise the power-factor to unity in an alternating current system in some other way than by the introduction of a commutator. The answer to that question is known to be negative.

If we consider a system of non-deformable electric circuits composed of any number p whatever, and at rest, the writer has shown (see *Lumiére Electrique*, 1907, page 5) that *whatever may be the complexity of the mutual inductions between the circuits considered by pairs*, the system can only absorb magnetizing power, and cannot supply any. The writer demonstrated, in fact, that the determinant which can be constituted with all the

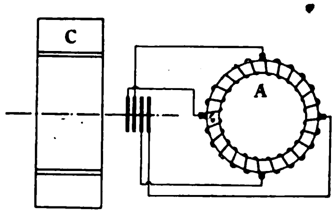


FIG. 2

induction coefficients is necessarily positive. A particularly well known case for two circuits is

$$\begin{vmatrix} L_1 & M \\ M & L_2 \end{vmatrix} > 0$$

Finally, the late Prof. Henry Poincaré—to whose attention the writer had brought the more general statement of the case, to the effect that the appearance and maintenance of any currents whatever in a system of stationary or moving circuits is impossible without the existence either of batteries or permanent magnets, or else of capacities or of means capable of modifying the internal connections of the circuits (such as by commutators) —demonstrated that a theoretical necessity was really involved (see *Lumiére Electrique*, March, 1907, page 293).

The possibility of raising the power-factor to unity without the use of a commutator would involve the negation of this necessity, and, therefore, could not exist.

In accordance with what has been said previously, with reference to the expression of the armature inductance in Fig. 1, under the form $L\ (\omega - \omega_1)$, it can be supposed, in order to obtain a first classical approximation, that the flux per phase on the armature-periphery is sinusoidal. But the distribution here considered is a theoretical one, which does not correspond to the real distribution. Let us begin by noting on what fictitious surface this distribution may be defined.

It is the general practice to consider the surface of the air gap, but that is not the point of view which the writer has adopted in his different studies. It has seemed to him that the distribution of flux which it was desirable to determine was that which is related to the geometrical surface containing the axes of the conductors subjected to inductive effects. Reference to Fig. 4, which shows a two-layer drum-winding, shows two cylindrical surfaces, S' and S'', which contain the axes of the conductors

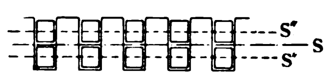


FIG. 4

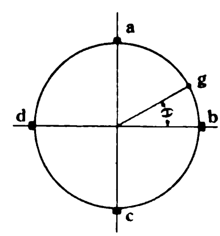


FIG. 5

subjected to induction. We ought, therefore, to consider the flux on the surfaces S' and S''. But the writer proposed previously (see *Lumiére Electrique*, January, 1907, page 6) to make an approximation which consists in considering only the midway surface S, situated between S' and S'', passing through points half-way down across the slots.

It will be noted that the magnetic flux referred to comprises the lines of force which other writers consider as constituting local leakage fluxes around the conductors; and that if we extend the surface S between the lateral connections of the armature, it comprises also the external leakage fluxes produced by the heads of the coils. We may imagine that the discontinuity caused by the teeth and slots gives rise to a special supplementary harmonic field. The result is that leakages can be represented by harmonics.

We have already given the name *magnetic periphery* to the

fictitious surface S of the armature. Diagrammatically, an armature having a commutator will be represented by a circle, whose circumference will be the magnetic periphery (see Fig. 5). It is on this magnetic periphery that the positions defined by the brushes a, b, c, d, will be indicated. The position of a radial line to any point, g, on the periphery, is defined by the angle $g\,o\,b = \theta$. Let $f\,(\theta)$ be the periodic function which represents the distribution per phase of the magnetic field normal to the surface S.

Simple calculations have already enabled the writer to establish (*see Lumière Electrique*, January, 1907, page 7), that the apparent inductance of the armature in Fig. 1, when supplied with two-phase currents, and when assumed to have an even number of sections, may be expressed at the angular velocity ω_1, as follows:

$$L\left(\omega - \omega_1 \frac{\int_0^{\pi/2} f\,(\theta)\,d\,\theta}{\int_0^{\pi/2} f\,(\theta)\,\theta\,d\,\theta}\right)$$

It should be carefully noted that, for a sinusoidal distribution, $f\,(\theta) = a \sin\theta$, the second term reduces to unity, whereas for a triangular distribution $f\,(\theta) = a\,\theta$, the quotient

$$\frac{\int_0^{\pi/2} f\,(\theta)\,d\,\theta}{\int_0^{\pi/2} f\,(\theta)\,\theta\,d\,\theta}$$

assumes the value $3/\pi$. In that case, the condition of zero inductance is obtained only at the velocity $\omega_1 = \pi/3\omega$.

It is proper to note, however, that a fractional pitch winding enables the velocity at which the inductance vanishes to be brought to a value nearer ω, and that, finally and especially, whatever may be the flux distribution on the magnetic periphery, the approximation to the theoretical expression $L\,(\omega - \omega_1)$ will become closer in proportion as the number of phases employed for supplying the armature in Fig. 1 is increased.

The very important question which remains to be considered in connection with the operation of the armature in Fig. 1 is that of commutation. We may here recall the manner in which that question was approached in the writer's study in 1901 (see *Eclairage Electrique*, page 294). Let λ be the full coefficient of self-induction of the sections of armature winding undergoing commutation under the brushes, *a*, *c*, through which is passing the current $I \sin \omega t$. This coefficient (λ), it should be noted, includes, in the case of windings of the drum type, the effect due to mutual induction between two sections in process of commutation under the brushes *a*, *c*. of opposite polarity. Now, let T represent the time that is consumed in the commutation of one section of winding. The condition which is ***necessary*** and ***sufficient*** in order to obtain perfect or "linear" commutation (which is gone into more fully in the article referred to), is that there should be available, in the winding sections which are in short-circuit, a reversal e. m. f. equal to $\frac{\lambda}{T} I \sin \omega t$.

Now the flux developed along the rectangular axis *b*, *d* is proportional to $\cos \omega t$. Consequently, the induction resulting from its periodic variation produces an e.m.f. in the sections short-circuited by the brushes a-c. which is proportional to $-\frac{d}{dt} \cos \omega t$ and, therefore, to $\sin \omega t$. This e.m.f. is constant for a given current $I \cos \omega t$. There is, therefore, a certain velocity ω_1, for which there is produced, exactly, in the commutated sections, the reversal e.m.f. necessary and sufficient, $\frac{\lambda}{T} I \sin \omega t$, to produce a perfect or linear commutation.

Below that velocity the reversal e.m.f. will be too high and commutating conditions will be produced which are analogous to those existing in a continuous-current dynamo when the brushes are set too far forward in the direction of rotation. Above that velocity, on the other hand, the reversal e.m.f. produced will be too weak, and the commutating conditions produced will be analogous to those which exist in a continuous-current dynamo when the brushes are not set sufficiently far forward in the direction of rotation, or even when they are set too far in the opposite direction. It will be pointed out later, that precisely this same condition of operation exists (namely

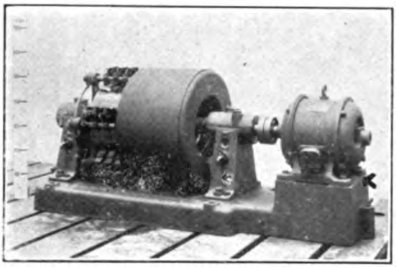


FIG. 3

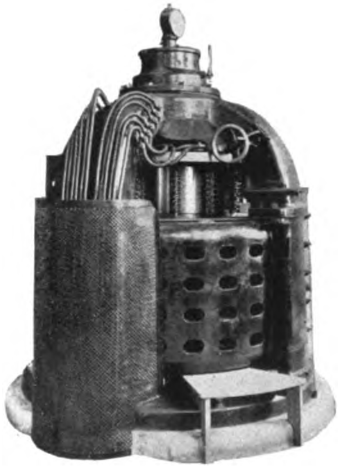


FIG. 9

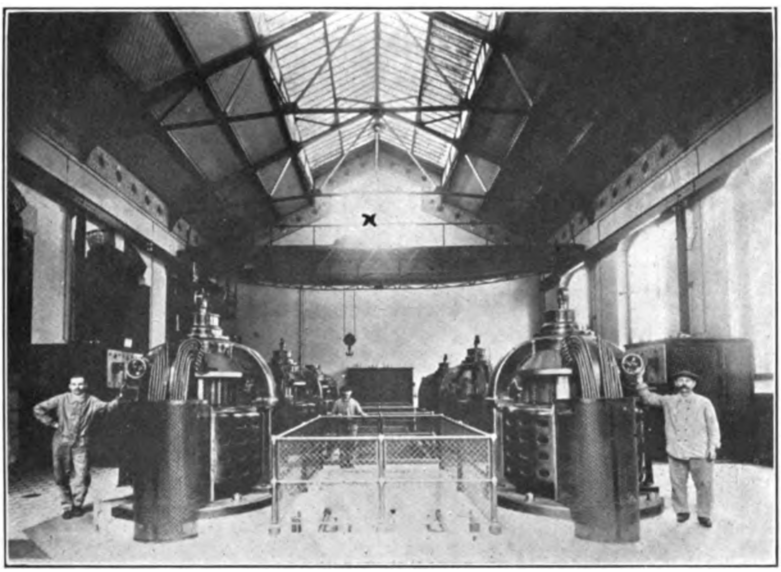


FIG. 8

[LATOUR]

insufficient reversal e.m.f.) when the armature in Fig. 1 is operating as a capacity, and it will be interesting to note that in the production of reactive current by a commutator we encounter the same commutating difficulties as the reduction of the normal armature reaction or the production of an armature reaction which assists the field excitation in a continuous-current dynamo.

It was shown by the writer (see ***Bulletin of the Société Internationale des Electriciens***, June, 1910, page 392) that in the case of an armature placed in a uniform air-gap, inside a laminated stator having evenly spaced slots, the e.m.f. necessary and sufficient to produce the perfect commutation of a current i is $\lambda\, I/T$, no matter what may be the distribution of the flux produced by the armature. This e.m.f. is equal rigorously to the e.m.f. which may be imagined to be induced in the winding sections under short-circuit, by reason of the rotation of the

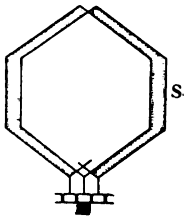


Fig. 6

armature in the flux developed by the armature as a whole. It should be well understood that the flux under consideration is that measured on the magnetic periphery of the armature, and on the portion of the surface comprised between the axes of the conductors of two contiguous sections in the region where commutation is taking place, as is shown in Fig. 6 (see the cross-hatched portion of the figure). There exists, in fact, a close relationship, in a continuous-current armature, between the coefficient (λ) of the winding sections under commutation and the flux produced by the entire armature through the shaded surface represented in Fig. 6, that is to say, in the interval comprised between two consecutive winding sections in the region in which commutation is taking place when unit current is passing through the armature. It is, moreover, by virtue of this close relationship that the writer has, since 1902, in the course of numerous controversies (see, for example, E. T. Z.,

1906, page 781; *Lumière Electrique*, 1902, page 53; *Electrician*, 1913, pages 105 and 325; *Elektrotechnik und Maschinenbau*, 1913, page 633), defended the very simple point of view according to which the matter of obtaining perfect commutation in a continuous-current dynamo depends substantially on the neutralization of the magnetic field of the armature, or, more properly, on the production of a mean resultant neutral field in the region where commutation is taking place. It is understood that the field is measured on the portion shown shaded in Fig. 6, on a surface S which passes about half-way across the armature slots, and not through a surface situated in the air gap. The exactness of this view seems to be recognized more or less explicitly at the present time.

Having shown that the determination of $\frac{\lambda}{T}\, I \sin \omega t$ in the case of Fig. 1 amounts to the evaluation of the e.m.f. induced in the short-circuited winding sections by the rotation of the armature in its own field, it is easy to determine, for a given flux distribution, the reversal e.m.f. which is necessary to obtain perfect commutation at the velocity ω_1. This knowledge of the flux distribution enables us to determine the reversal e.m.f. which is available by reason of the variation of the flux which is proportional to cos ωt, along the direction perpendicular to the axis of the brushes a, c. We can then finally determine the difference between these two e.m.f's. and this is what interferes with commutation.

Let $f(\theta)$ be the flux distribution. It will be found by a simple reasoning that in an armature wound with an even number of sections (full pitch winding) the e.m.f. under the brushes resulting from an excess or lack of reversal e.m.f. is proportional to

$$\left(\omega - \omega_1 \frac{f(\theta)_{\theta = \pi/2}}{\int^{\pi/2} f(\theta)\, d\,\theta} \right)$$

If we make the theoretical assumption that $f(\theta) = a \sin \theta$, it will be readily seen that the quotient $\dfrac{f(\theta)_{\theta=\pi/2}}{\int_0^{\pi/2} f(\theta)\, d\,\theta}$ reduces to

unity, and that perfect commutation is obtained at synchronism for the condition $\omega_1 = \omega$.

If we suppose that $f(\theta)$ is of the form $a\,\theta$, which is nearer the actual condition, it will be found that perfect commutation is obtained at the velocity $\omega_1 = \frac{\pi}{4}\,\omega = 0.79\,\omega$. However, the conditions are changed if the number of phases employed for supplying current to the armature in Fig. 1 is increased. With six phases, we find, for the velocity of perfect commutation

$$\omega_1 = \frac{\sqrt{3}}{2}\,\omega = 0.86\,\omega$$

and finally, for twelve phases, we find $\omega_1 = \omega$. By adopting a fractional pitch for the winding of the armature it is possible to approach more rapidly the condition $\omega_1 = \omega$. It is important to note that if the commutation is not perfect at synchronism in all cases, it is because we are not dealing, in general, with a uniform revolving field, in consequence of a non-sinusoidal distribution of flux on the magnetic periphery of the armature. The simple reasoning which the writer followed in a first approximation (1900–1901), and in which he asserted that commutation must always be perfect at synchronism when there is a real revolving field, is exact, for the very reason that the variation of flux in the short-circuited sections vanishes at synchronism.

Everything that can be done to obtain a perfect revolving field (such as increasing the number of phases and using fractional pitch winding) unquestionably assists in insuring perfect commutation at exact synchronism.

When the revolving field produced by a rotor having a commutator is imperfect, the commutation is disturbed at synchronism under conditions equivalent to those wherein it would be disturbed by an external imperfect revolving field produced by the stator surrounding it.

In reality, the increase in the number of phases for the supply of current to the rotor of a commutator machine, as set forth in the writer's German patent No. 145,433 of 1901, is related rather to a specific purpose, and it has less immediate relation to commutation. It may be interesting to note the principal reasons for this.

In the first place, in increasing the number of phases for

supplying current to the rotor, the current to be commutated per phase for a given total current in the armature is materially diminished. The frictional surface on the periphery of the commutator remains the same in the two cases, but it is differently distributed. The result of reducing the current per phase is that the resistance of a single line of brushes in the case of a bipolar armature, or of the assemblage of lines of brushes coupled in parallel in the case of a multiple-wound armature, increases with the number of phases. Now, the increase of this resistance, as is well known, is favorable to good commutation, so long as the machine is not working at a theoretical load corresponding to perfect commutation.

In a load which does not correspond to perfect commutation, there exists, so to speak, in the short-circuited sections, a disturbing e.m.f. which is equal to the difference between the e.m.f. necessary to produce perfect commutation and that which

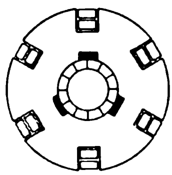


Fig. 7

is actually induced; it is this parasitic e.m.f. which is the real cause of the excessive heating and of the sparking at the brushes.

With reference to sparking, Mr. F. Carter and the writer (see the *Electrical World*, March 31st, 1910, page 804, and *Bulletin de la Société Internationale des Electriciens*, April 6th, 1910, page 276) have advanced the opinion that the effects of a given parasitic e.m.f. increase, other things being equal, with the value of the quotient l of certain determinants composed of the coefficients of self and mutual induction of all the closed circuits in the machine. This quotient l itself has the dimensions of a coefficient of self-induction, and in a continuous current machine it is generally but slightly lower than the coefficient of leakage self-induction of two consecutive winding sections *placed in contiguous slots*. In an armature supplied with polyphase currents, however, the quotient l may fall much below that value.

In this connection reference may be made to Fig. 7, which is the reproduction of a diagram already published by the writer

(see A. I. E. E. TRANSACTIONS, 1903, page 583). The diagram represents an armature with a drum winding composed of twelve sections, supplied by three-phase currents. It will be easily seen that, as the width of the brushes exceeds the width of the commutator segments, there is always, at any instant, at least one short-circuited section per slot. Armatures having as few as three slots per pole are seldom used, but if we adopt a higher number of phases, preferably an odd number (7 or 9, for example, as indicated in the writer's A. I. E. E. communication of 1903) the remarks relative to the conditions shown in Fig. 7 can be extended to the case of an armature having a number of slots actually used in current practice. Under those conditions, the quotient l becomes lower than the coefficient of self-induction due to leakage between two sections *placed in the same slots*. The parasitic e.m.f. will then produce practically a simple short-circuit current as if the armature was at rest or revolving slightly. Under these conditions, we will have the sparkless commutation which I named "squirrel-cage commutation."

The three types of a-c. polyphase commutator machines which can be rationally constituted by taking synchronism as the mean working condition, are analogous to continuous-current machines, namely, the shunt machine, the series machine, and the compound-wound machine. The theory of these machines was published by the writer in 1902 (see *Eclairage Electrique*, 1902, pages 50 and 358), and different authors have gone over the subject since in a more detailed manner. When these machines are working above or below synchronism, then, from the point of view of commutation, it is necessary to take into consideration the e.m.f. induced by the *resultant* field of the stator and rotor in the short-circuited winding sections, and to judge the commutation accordingly. If a machine is intended to have the greatest possible range of speed, then it is immediately obvious that it is important to arrange matters in such way that synchronism shall correspond to a speed of perfect operation so far as commutation is concerned. Allowance can then be made for equal values of slip above and below synchronism, and in this way the allowable variation of speed becomes greater. With an absolute slip of 20 per cent, for example, it is possible to obtain speed variations in the ratio of two to three.

When the slip is to be materially increased, the width of the brushes should be reduced as much as possible, in order that

the e.m.f. induced between the opposite edges of the brush may be as low as possible; but for mechanical reasons it is scarcely practical to reduce the thickness of the brushes to less than 9 to 10 mm.

This minimum width of brushes being a limitation, it is desirable (for the same e.m.f. developed between the two edges of the brush) to reduce this e.m.f. in some way by adopting a type of winding which allows the commutator segments to have a width of half that of the brush (see the writer's article in the *Electrical World* of December 3rd, 1904). As a rule, commutator segments of 4.5 to 5.0 mm. will be used.

With brushes of good quality the e.m.f. allowable between the segments under those conditions will be 1.5 volts. This e.m.f. allows high values of slip to be attained without necessitating a commutator of excessive size.

The writer has devoted much attention in the last ten years to a number of installations in which polyphase machines with commutators have been used. Figs. 8 and 9 represent an installation made about five years ago at the pumping station of the City of Paris. The machines are 500-h.p. motors supplied with three-phase 50-cycle current and operating at speeds ranging between 450 and 700 rev. per min., the synchronous speed being 600 rev. per min. The speed regulation is obtained by shifting the brushes. The rotor is supplied with twelve phases by means of twelve equidistant brush-holders. The total width of the commutator is 40 cm. The operation of the machines is perfect in every respect.

In concluding, the writer believes that the following historical résumé of his part in development of polyphase commutator machines may be of interest.

The English patent to Wilson (No. 18,525, of 1888) describes a polyphase commutator motor having the stator and the rotor connected directly in multiple without any transformer. According to the inventor, a squirrel-cage winding or a short-circuited winding might, if necessary, be placed on the rotor or on the stator or else on both of them at the same time if it were desired to operate the motor at or very near synchronous speed. The writer took up this same mode of connection later (French patent No. 306,229 of 1900) from a more modern point of view. His analysis led him to foresee the importance of lowering as much as possible the e.m.f. in action at the commutator by employing either transformers, a special tension-lower-

ing device, or else sectional windings placed on the stator as means of supplying current to the rotor. In a German patent of 1891 (No. 61,951 to Georges) a series polyphase commutator motor is described. The writer has also introduced in that arrangement a series transformer between the stator and the rotor. Later, the writer adopted the plan of constructing these transformers with an air-gap, in order to improve the characteristics of the motor; and the connections employed are of the star-delta type, as shown in Fig. 10 (German Patent, No. 237,849).

The star-delta connection enables one to regulate the speed in a practical way, within wide limits, by simply shifting the brushes. The star connection is used for starting and for running at lower speeds; the delta connection is used at higher speeds.

Besides the shunt and series connections, mentioned in the two patents just referred to, the writer has also indicated how a compound connection could be used between the stator and the rotor (German patent No. 154,509 of 1901) and has favored the provision of a rotor with a greater number of phases than are obtainable directly from the supply mains (German patent No. 145,433 of 1901). This greater number of phases is obtained by means of a transformer, or else, in the case of a shunt machine, by means of auxiliary windings placed on the stator.

Finally, the writer has also proposed the use of all these kinds of machines as generators, and has called attention to their advantages in regard to their coupling in multiple and their compounding. Before the war, the writer had begun the construction of 100 kv-a. three-phase generators, which were to operate as boosters for mains supplying three-phase currents of 50 cycles. The writer is confident that this question of a-c. commutator generators, *in which, by the way, the commutator is relatively very small*, is a development which is sure to command attention in the near future.

II—Commutation in Single-Phase Machinery

Let us suppose that the armature in Fig. 1 is supplied with a simple alternating current through two brushes *a*, *b*, placed 180 deg. apart, instead of being supplied with two-phase currents (see Fig. 11). The armature-reactance then retains the same value $L\omega$, whatever may be the angular velocity ω_1. But, if we place, 90 deg. from the brushes *a*, *b*, some supplemental brushes *c*, *d*, connected together by a short-circuit connection (see Fig. 12), the armature-reactance then takes, as a first ap-

proximation, the value $L\left(\omega - \frac{\omega_1^2}{\omega}\right)$. It therefore vanishes when synchronism is attained and becomes negative above synchronism.

Thus, when a current $I \sin \omega t$ is sent through the armature by means of the brushes *a*, *b*, there is, in consequence of the arrangement of the short circuited brushes *c*, *d*, an e. m. f., $-L \frac{\omega_1^2}{\omega} I \cos \omega t$ which is in opposition to the e. m. f. of self-induction $L \omega I \cos \omega t$, and, consequently, balances it at synchronous speed. The result is the same as if two-phase currents were sent into the armature. This phenomenon was discovered by the writer in 1901. This e. m. f., $L \frac{\omega_1^2}{\omega} I$ is produced by the fol-

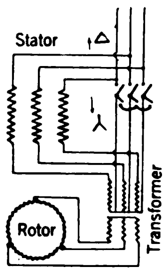


FIG. 10

FIG. 11

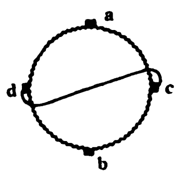


FIG. 12

lowing instrumentality. Let *M*, as before, represent the coefficient of mutual induction between the sections of winding which are in process of commutation under the brushes *a*, *b*, in which there is a reversing current $\frac{I}{2} \sin \omega t$, and the sections in circuit between the brushes *c*, *d*. Let again *n* be the number of sections of armature winding. At the speed ω_1 the duration *T* of the short-circuit in any section short-circuited by the brushes will be, $T = \frac{2\pi}{\omega_1 n}$. The induced e. m. f. between the brushes *c*, *d*, due to the mutual induction between the sections undergoing commutation under the brushes *a*, *b*, and the sections which are in circuit between the brushes *c*, *d*, will be,

$$\frac{M I \sin \omega t}{y} = \frac{M}{2\pi} n \omega_1 I \sin \omega t$$

This e. m. f. will produce, in the conductor connecting the brushes c, d, a short circuit current which is $\frac{\pi}{2}$ out of phase with respect to that e. m. f. $\frac{M}{2\pi}\,\frac{\omega_1}{L\,\omega}\,I\cos\omega\, t$. This current, in phase with $\cos\omega\, t$ is, in turn, commutated under the brushes c, d, and the mutual induction between the armature windings short-circuited by the brushes c, d, and the windings short-circuited by the brushes a, b, develops, between the brushes a, b, an e. m. f.,

$$\frac{Mn}{2\pi}\,\frac{\omega_1}{L\,\omega}\cdot\frac{Mn}{2\pi}\,\omega_1\, I\cos\omega\, t=\left(\frac{Mn}{2\pi}\right)^2\frac{1}{L}\,\frac{\omega_1^2}{\omega}\, I\cos\omega t$$

If we suppose the flux to be distributed sinusoidally we find that $\frac{Mn}{2\pi}=L$, as we have already noted; and the e. m. f. induced in consequence of the rotation of the armature becomes equal to $L\,\frac{\omega_1^2}{\omega}\, I\cos\omega\, t$. In reality, the distribution of fluxes on the magnetic periphery is not sinusoidal.

Let $f(\theta)$ express the periodic function which represents the actual distribution of flux, and let R represent the resistance of the armature between the brushes. The writer has already shown, by simple calculations (see *l'Eclairage Electrique*, January, 1907, page 811) that the armature-reactance at the velocity ω_1 is, in reality equal to,

$$L\left[\omega-\left(\frac{\int_0^{\pi/2} f(\theta)\, d\,\theta}{\int_0^{\pi/2} f(\theta)\,\theta\, d\,\theta}\right)^2\frac{1}{1+\frac{r^2}{L^2\,\omega^2}}\,\frac{\omega_1^2}{\omega}\right]$$

On the assumption that the flux has a triangular distribution, $f(\theta)=a(\theta)$, it will be found that the quotient

$$\frac{\int_0^{\pi/2} f(\theta)\, d\,\theta}{\int_0^{\pi/2} f(\theta)\,\theta\, d\,\theta}$$

is equal to $\frac{3}{\pi}$ and that the armature-reactance may be expressed as follows:

$$L\left(\omega - \frac{9}{\pi^2} \frac{1}{1 + \frac{r^2}{L^2\,\omega^2}} \frac{\omega_1^2}{\omega}\right)$$

The armature-reactance vanishes, under those conditions, when the velocity attains the value $\omega_1 = \frac{\pi}{3}\sqrt{1 + \frac{r^2}{L^2\,\omega^2}}$.

Generally, $\frac{r}{L\,\omega}$ is very small, and it might be said that the reactance vanishes when $\omega_1 = \frac{\pi}{3}\,\omega$, exactly as in the case when the machine is supplied by two-phase currents.

Let us consider now the important question of commutation. The reversal e. m. f. necessary for commutating the current $I \sin \omega t$ under the brushes a, b, in Fig. 12, is induced by variation of the flux in phase with $\cos \omega t$ which exists along, c, d.

If we imagine the distribution of flux to be represented by the function $f(\theta)$ it will be seen, from what precedes, that the commutation under the brushes a, b, requires, in the case of an armature of even (full) winding pitch, a reversal e. m. f. which is proportional to $f(\theta)_{\theta = \pi/2}\ \omega_1$.

On the other hand, it is easily shown, after calculating the current in the short circuit, c, d, that the e. m. f. induced by the variation of flux along c, d, in the section short-circuited by the brushes a, b, is proportional to

$$\frac{\left(\int_0^{\pi/2} f(\theta)\, d\,\theta\right)^2}{\int_0^{\pi/2} f(\theta)\,\theta\, d\,\theta}\ .\ \omega_1$$

The ratio of the two e. m. f. considered, is therefore equal to

$$\frac{\left(\int_0^{\pi/2} f(\theta)\, d\,\theta\right)^2}{f(\theta)_{\theta = \pi/2} \times \int_0^{\pi/2} f(\theta)\,\theta\, d\,\theta}$$

Assuming a sinusoidal flux-distribution ($f(\theta) = \alpha \sin \theta$), it is actually found that this ratio is equal to unity, so that the e. m. f. necessary to insure perfect commutation under the brushes a, b, is always equal to the e. m. f. actually induced by the field variation along c, d. But, if we assume that the flux-distribution is triangular $f(\theta) = a\theta$, it will be found that the ratio, above mentioned, becomes equal to $\frac{3}{4}$ simply.

Under those conditions the e. m. f. actually induced in the armature sections which are short circuited by the brushes a, b, is not sufficient to insure perfect commutation of the current $I \sin \omega t$, and 25 per cent of the volume of that current will have to be commutated by brush-resistance.

Let us consider the commutation obtained under the brushes c, d. The e. m. f. necessary to obtain perfect commutation is proportional to the current passing through the short-circuit connection between the brushes c, d, and proportional to the velocity ω_1.

As the current in the short-circuit connection between the brushes c, d, is already proportional to the velocity ω_1, the e.m.f. necessary is proportional to ω_1^2; and, taking into account the flux distribution, it will be found to be proportional to

$$\frac{f(\theta)_{\theta=\pi/2} \int_0^{\pi/2} f(\theta)\, d\theta}{\int_0^{\pi/2} f(\theta)\, \theta\, d\theta} \quad \frac{\omega_1^2}{\omega}$$

On the other hand the e.m.f. induced by the variation of flux along a, b is proportional to

$$\int_0^{\pi/2} f(\theta)\, d\theta .\ \omega$$

Consequently the e.m.f. causing disturbance in the armature-sections which are short-circuited under the brushes c, d, which is the result of either excess or insufficiency of the e.m.f. of reversal, will be proportional to

$$\left(\omega - \frac{\omega_1^2}{\omega} \; \frac{f(\theta)_{\theta=\pi/2}}{\int_0^{\pi/2} f(\theta)\, \theta\, d\theta} \right)$$

Assuming a sinusoidal flux distribution $f(\theta) = \alpha \sin \theta$, perfect commutation will actually take place when, $\omega_1 = \omega$.

In the case of triangular flux distribution $f(\theta) = \alpha\,\theta$, we have

$$\frac{f(\theta)_{\theta=\pi/2}}{\int_0^{\pi/2} f(\theta)\,\theta\,d\,\theta} = \frac{12}{\pi^2}$$

and perfect commutation will be obtained when $\omega_1 = \frac{\pi}{\sqrt{12}}\,\omega$

In the case of an armature wound with fractional pitch winding in which each section corresponds to an arc equal to $\pi - \alpha$ instead of a half circumference, π, if we assume that a winding of this character produces a trapezoidal flux-distribution, the results obtained are as will be described.

With regard to the commutation obtained under the brushes a, b, the expression of the ratio of the e.m.f. actually induced to the e.m.f. necessary to obtain perfect commutation, will now be as follows:

$$\frac{3\left(\frac{\pi}{2} - \alpha\right)^2\left(\frac{\pi}{2} + \alpha\right)^2}{(\pi - \alpha)^3\,(\pi + 2\,\alpha)}$$

A numerical application, such as for instance, when $\alpha = \frac{\pi}{3}$, gives 0.92 for the value of this ratio, which is quite near unity, and, consequently, there is a perceptible improvement as compared with full pitch winding, which gives 0.75 for that ratio. With regard to the commutation obtained under brushes c, d, the disturbing e.m.f. in the sections which are short circuited by the brushes c, d, and which results from either excess or insufficiency of the e.m.f. of reversal, becomes proportional to

$$\left(\omega - \frac{\omega_1^2}{\omega}\;\frac{12}{(\pi - \alpha)\,(\pi + 2\,\alpha)}\right)$$

A numerical application, such as that corresponding to $\alpha = \frac{\pi}{3}$ leads to the conclusion that perfect commutation will

be obtained for a velocity $\omega_1 = \frac{\pi}{\sqrt{10.8}}\,\omega$, which is very near that of synchronism.

In addition to the use of armatures with fractional pitch windings, (recommended by the writer in 1905; See *Eclairage Electrique*, page 125) the writer had proposed, in January 1903, the arrangements shown in Figs. 13, 14 and 15, which have a certain analogy with the phase-multiplications previously proposed by the writer for supplying current to the rotor in the case of polyphase machines.

It will be seen at once that, in consequence of the circulation of a current which is 90 deg. out of phase in the short-circuit connections between the brushes, a rotating field will be available at synchronism; and, by analogy with what has previously been said in regard to armatures provided with commutators and supplied by polyphase currents, it may be said that the

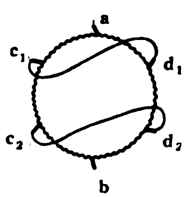


FIG. 13

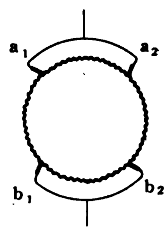


FIG. 14

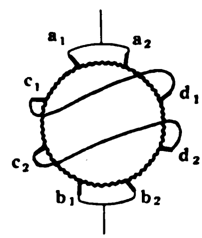


FIG. 15

problem of securing perfect commutation at synchronism comes back to the realization of a perfect rotating field. This result is attained by utilizing, conjointly, the arrangements shown in Figs. 13 or 15 and a suitable fractional pitch winding.

From a clear understanding of the operation of the armature shown in Fig. 12, it will readily be seen how single-phase commutator machines similar to polyphase commutator machines, may be made with all kinds of windings and connections, shunt, series or compound, having a power factor equal to unity. Figs. 16 and 17, show respectively the shunt and series arrangements.

The machines which have been put on the market are the shunt and series motors, such as for example, those described in U. S. Patent No. 1016021. The writer has devoted attention to the construction of a large number of these motors which have, however, been used more for continuous operation on

ordinary power circuits than for electric traction by single-phase current.

Fig. 18 is taken from a photograph of a type of motor of 200 h.p., 600 rev. per min., 50 cycles designed for continuous service, of which a considerable number have been constructed in the last 10 years. The number of sets of brushes and their connections correspond to the arrangements shown in Fig. 15. The speed-regulation, between 400 and 750 rev. per min., is obtained simply by shifting the brushes in accordance with the method of regulation described by the writer in 1903.

In motors which are intended to be regulated by shifting the brushes, it is important to take into account the action of the field produced by the stator, considered by itself, on the commutation of the rotor. In reality, in order that this action may not produce any special disturbance when a given shift is made in the brushes, it is necessary and sufficient that the field produced by the stator, considered by itself, should correspond to

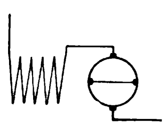


FIG. 16

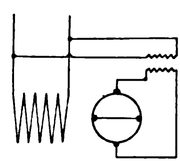


FIG. 17

a sinusoidal distribution on the magnetic periphery of the rotor. This result will be obtained, with a close degree of approximation, by winding the stator partially on an arc equal to about $\frac{2\pi}{3}$ per pole, and it will be obtained more perfectly in motors of large power by the plan, already mentioned, of arranging for a sinusoidal variation in the number of conductors placed in the slots of the stator, which are supposed to be evenly spaced.

The term "*compensated repulsion-motor*" was applied, by the writer, to the motor shown in Fig. 17 many years ago, because he appreciated, at that early date, the close relationship which is recognized generally today, between that motor and the repulsion-motor. It is proper, however, to consider the repulsion-motor, not in the primitive form given to it originally by Elihu Thomson, but in the form which it assumes when the stator of an induction motor is adopted in its construction.

The writer published his first theory of this form of repulsion-motor (see *E. T. Z.*, June 11, 1903) before entering upon a detailed consideration of the compensated repulsion-motor. The great peculiarity of the repulsion-motor when constructed with the stator of an induction motor, is that a rotating field is produced in that type of motor at synchronism, and that, at that speed, the existence of that rotating field insures perfect commutation. Before the publication, by the writer, of the fundamental theory, the only theory known was that of Steinmetz, which related to the repulsion-motor constructed with pole-pieces, and which consequently did not foresee the formation of a rotating field and its consequences.

Of course, in order to obtain a perfect rotating field, it is necessary to resort to the precautions which have just been mentioned and discussed with respect to the compensated repulsion- motor, namely, the rotor must have fractional pitch winding and multiple short circuits; and the stator must have a sinsudoidal distribution of conductors.

With regard to the motors having a high power-factor, shown diagrammatically in Fig. 16, it is the shunt type of motor which has found most numerous commercial applications. The supply of current to the rotor is effected, as already indicated in the case of polyphase motors, either by a transformer or by an auxiliary winding placed on the stator.

The detailed theory of this motor, published ten years ago by the writer, (see *Eclairage Electrique*, January 1907, page 8) showed the great importance of flux distribution in that motor from the point of view of the torque produced, and also showed that great overload capacity may be given to this motor.

It is interesting to note that this motor can be constructed for very large powers with a commutator of very small dimensions when a heavy torque is not necessary in starting. If proper care has been taken in the design of the winding and in the distribution of the brushes on the commutator, this motor can operate at full load *with extraordinary commutation.* The drawback of a commutator is therefore, not as serious as might be supposed. On the other hand this motor has in its favor the following advantages:

1. It can supply a reactive current to the electrical mains,
2. Its overload capacity is much higher than that of the induction motor.

These advantages are sufficiently real, in the opinion of the

writer, to warrant his considering quite practicable an electrical traction system based upon the use of single-phase current of 50 or 60 cycles involving the conversion, on the locomotive itself, of the single-phase current into a continous current by a motor-generator set comprising a commutating shunt motor. By employing high speeds, these motor-generator sets can be made quite light.

The fact that regulating resistances and all accessory apparatus are eliminated, and also the possibility of recovering energy at all speeds without any special complication, render this system more attractive than it might seem to be at first glance. The writer expects to return to this subject later with comparative figures.

With regard to electric traction by the direct use of single-phase alternating current, although that system does not appear

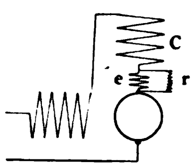


FIG. 19

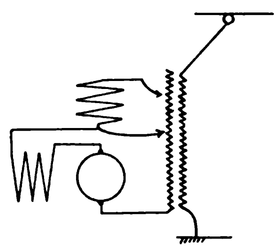


FIG. 20

to remain in high favor in the United States in recent years, it may be worth while to refer to the two types of single-phase motors to which the writer has given attention.

The electrical world is quite familiar today with the motor having a local commutating field (see Fig. 19) which has, outside of the compensating winding *c*, a local winding *e*, shunted by a resistance *r* in such a way that this local winding produces a field that is out of phase above the sections which are undergoing commutation. With a frequency of 15 or 16 cycles, the loss of power in the resistance *r* can then be rendered negligible. This motor is then, undoubtedly, as the writer has shown (see *E. T. Z.*, Nov., 1912, page 1231) the best variable speed motor so far as commutation is concerned. That motor has been constructed especially in Switzerland by the Maschinenfabrik Oerlikon, but motors of similar type have been constructed in France by M. Perret, in co-operation with the writer.

PLATE VI.
A. I. E. E.
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FIG. 22

[LATOUR]

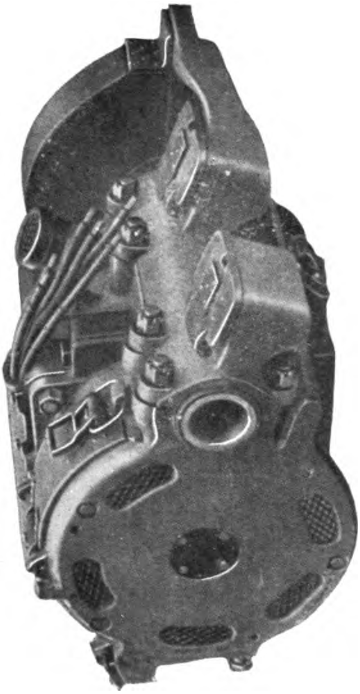

FIG. 21

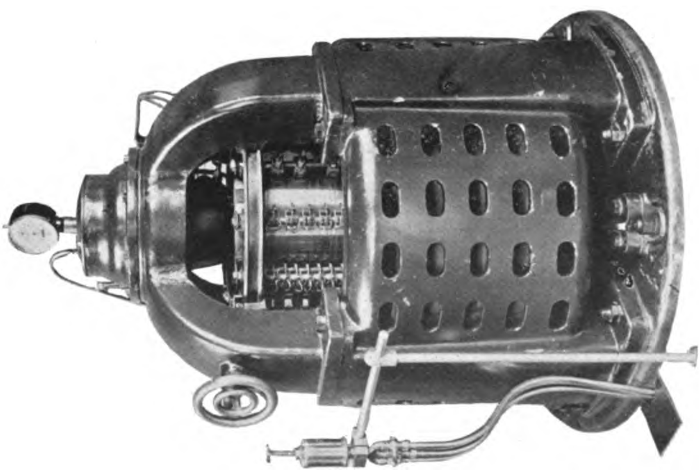

FIG. 18

At a frequency of 25 cycles the introduction of the resistance *r* would occasion too high a loss of energy, and the writer then gives preference to a motor which is designated by him the "elliptical field series motor," which is represented diagrammatically in Fig. 20 (see also U. S. Patent 841257 and *E. T. Z.*, 1906, volume 27, page 89). As the diagram indicates, the arrangement of connections of that motor implies the presence of a transformer *T* for supplying current to the motor. The dephased commutating field is produced by the compensating winding itself. The resemblance of this motor with the motor constructed by Mr. Alexanderson in America, will be readily noted.

Subsequently to the introduction of this type of motor by the writer in German technical publications, under the name of "Series-motor with Elliptical Field" (see article by the writer in *E. T. Z.* 1906, volume 27 page 89) German authors gave it the name of "doppel gepeist" ("double fed"), which seems to have

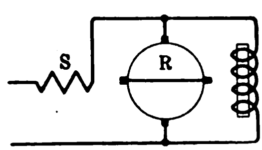

FIG. 23

become more or less current to-day in America. Nevertheless, it seems preferable to the writer to retain in the designation of the motor, the peculiarity which gives it good commutation insomuch as good commutation is the matter of utmost importance in commutating motors. It seems proper to the writer also that this designation should suggest a trace of the difficulty which inspired the very conception of the motor itself.

Figs. 21 and 22 are reproduced from photographs of a 75-h.p. motor for an electric railway of narrow gauge (1 meter) constructed in accordance with the writer's inventions, and of which a considerable number have been in operation for several years. These motors have eight poles and run at 750 rev. per min. with 320 volts. The width of the commutatoris 240 mm. The writer has also constructed, for 25-cycle electric traction lines, some compensated repulsion motors with a reactance coil *l* in parallel with the exciting brushes (see Fig. 23), this arrangement being one proposed by the writer in 1903.

The reactance coil is useful at the time of starting because it allows a greater excess of current in the induced circuit (stator) without requiring an excessive strength of inducing field (rotor), which latter is shunted at low speed. The result is that, ***automatically,*** as foreseen by the writer, there is, at the time of starting, a low flux with a heavy current, so that the commutator suffers less. Moreover, the rectance coil limits the hyper-synchronous speed of the motor, which is always to be feared from the point of view of commutation. The limiting hyper-synchronous speed is exactly that for which the reactance of the coil *l* comes into resonance with the capacitance of the rotor. The adjustments are made in such a way that this hyper-synchronous speed cannot exceed a rise of 50 per cent above synchronism. Motors of this type, which have been in practical operation about 10 years under particularly severe conditions, have given entire satisfaction.

It is well known that the drawback of a single-phase traction motor designed for 25 cycles, is the necessity of a very large commutator, owing to the high starting torque required. The volume of the commutator is indeed directly proportional to the frequency of current used, and to the starting torque required (see the writer's article in the *Electrical World*, Dec. 3, 1904). The commutation may, however, be very good at normal load, and it is the belief of the writer that opinions have been much too pessimistic on that point. At the same time, it is not our intention at this time to defend single-phase traction, which was only an incidental object of this paper.

PROCEEDINGS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS

Vol. XXXVII Number 3

MARCH, 1918

Cleveland Meeting, March 8, 1918
See Section I, page 65

FUTURE MEETINGS

CLEVELAND MEETING

March 8, 1918

PITTSBURGH AND NEW YORK MEETING

April 9 and 12, 1918

ANNUAL MEETING

New York, May 17, 1918

ANNUAL CONVENTION

Atlantic City

Last week of June

PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXVII
Number 3

MARCH, 1918

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GEORGE R. METCALFE, Editor.

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVII | MARCH, 1918 | Number 3

THE CLEVELAND MEETING
MARCH 8, 1918

The 338th meeting of the A. I. E. E. which will be held in Cleveland, March 8, is an inter-section meeting in which the Cleveland, Pittsburgh, Toledo, Toronto and Detroit Sections of the Institute will participate.

The meeting will include two technical sessions, one in the afternoon and one in the evening, and an informal dinner will be held between the two sessions.

The regular monthly meeting of the Board of Directors, and various committee meetings as specified in notices to committee members will be held previous to the afternoon technical session.

The papers to be presented on behalf of the A. I. E. E. cover the subjects of Underground Distribution, Capacity of Rolling-Mill Motors and Selection of Auxiliary Motors for Steel Mills.

There will also be a paper presented on behalf of the A. I. and S. E. E. entitled, "Steel-Industry Motors Standardized," by Standardization Committee of A. I. & S. E. E.

The joint session of the two societies will be held in the evening at 8:30 p. m.

At the informal dinner between the technical sessions addresses will be given by prominent speakers on some timely topics.

Members of the A. I. and S. E. E. are cordially invited to attend the afternoon session and the subscription dinner.

PROGRAM

Reprints of the papers to be presented will be available without charge, and will be distributed at the entrance of the meeting room.

Friday, March 8

10:30 A.M.

Committee meetings as per notices to committee members.

1:00 P.M.

Registration office opens.

1:30 P.M.

Board of Directors meeting.

2:30 P.M.

Technical Session

Design of Underground Distribution for Electric Light and Power, by George J. Newton.

Some Considerations in Determining the Capacity of Rolling-Mill Motors, by Robert F. Hamilton.

6:30 P.M.

Informal dinner in the dining room of the Electrical League, in the Hotel Statler, $1.50 per cover.

8:30 P. M.

Selection of Steel-Mill Auxiliary Motors and Control as Affected by Mechanical Features of the Drive, by J. D. Wright.

"Steel-Industry Motors Standardized," by Standardization Committee of A. I. & S. E. E.

Informal Dinner

For the convenience of members and guests attending the Cleveland Meeting an informal dinner will be held in the dining room of the Electrical League, in the Hotel Statler, Friday evening, March 8th, at 6:30 p. m. The dinner will be served promptly in order not to interfere with the evening technical session.

The subscription price is $1.50 per person and tickets will be on sale at the Registration Headquarters of the Institute at the Hotel Statler.

No definite seating arrangements will be made but reservations will be arranged upon request to the Dinner Committee at Registration Headquarters prior to 5:00 p. m. Friday, March 8th.

Addresses on interesting topics will be given by some prominent electrical engineers.

Hotel Reservations

Members should make their own reservations for hotel accommodations. As Cleveland hotels are unusually crowded at this season members are advised to make reservations well in advance.

The principal hotels are the Statler, the Hollenden, the Olmsted and the Winton.

Transportation

No special transportation rates are available, and members should consult their local ticket agents regarding routes and rates. Parlor and sleeping car accommodations should be engaged in advance.

FUTURE A. I. E. E. MEETINGS

April Meeting: The April meeting will be an inter-section meeting held in Pittsburgh April 9th and New York April 12th. Two papers will be presented: "The Physical Conception of the Operation of the Single-Phase Induction Motor," by B. G. Lamme and "The Theory of the Phase Converter and the Single-Phase Induction Motor," by R. E. Hellmund.

May Meeting: The May meeting will be the Annual Business Meeting held at Institute headquarters, New York. The feature of chief interest at this meeting will be the ceremonies in connection with the presentation of the Edison Medal.

Annual Convention: The Annual Convention will be held at Atlantic City, covering a period of three days during the last week in June. Complete program and dates to be announced later.

FUTURE SECTION MEETINGS

Baltimore.—March 18, 1918. Subject: Air Brakes.

Chicago.—March 25, 1918, Speaker: Charles F. Burgess. Subject: Electro-Chemical Processes."

Philadelphia.—March 11, 1918, Engineers Club. Subject: Some Electrical Problems of the Navy.

Portland.—April 2, 1918. Mr. J. B. Fisken will address the meeting.

A. I. E. E. MIDWINTER CONVENTION

The sixth annual midwinter convention of the A. I. E. E. was held at Institute headquarters, New York, on the 15th and 16th of February, 1918. The attendance was about 400.

President E. W. Rice, Jr. formally opened the convention at 10:30 a. m. Friday the 15th. He devoted his remarks to the coal and transportation situation of the country and pointed out that electrification of all steam roads would result in a saving of 100,000,000 tons of coal per year, a quantity three times as great as the total coal export of the United States for 1917. President Rice's address in full will be found elsewhere in this issue.

President Rice then opened the technical session by introducing G. A. Burnham who presented the paper entitled *Rating and Selection of Oil Circuit Breakers*, by E. M. Hewlett, J. M. Mahoney and G. A. Burnham. This paper discusses the interpretation of the A. I. E. E. Standardization Rules covering the rating of oil circuit breakers and the variable factors involved in the selection of breakers for various systems. Vice-President B. A. Behrend then took the chair and opened the discussion in which the following men took part: E. M. Hewlett, J. M. Mahoney, H. R. Summerhayes, W. W.

Willard, Bassett Jones, Fred C. Hanker, Philip Torchio, P. M. Lincoln, R. E. Doherty, F. L. Hunt, H. H. Dewey, H. D. James, N. L. Pollard, N. J. Neall, E. G. Merrick, P. H. Adams, Ira M. Cushing and L. T. Robinson.

Vice President Behrend called the afternoon session to order at 2:30 p. m. After a few remarks he turned the meeting over to Vice President L. T. Robinson. At this session known as the Meters and Measurements Session four papers were presented by the authors. *A New Standard for Current and Potential*, by C. T. Allcutt. This paper describes a new secondary standard—a Wheatstone bridge which will balance for but one value of current—which is proposed as a substitute for the standard cell. *The Thermoelectric Standard Cell*, by C. A. Hoxie. A description of a means of obtaining a secondary standard of e. m. f. by utilizing the e. m. f. of a thermocouple. The two papers were then discussed by the following men: Clayton H. Sharp, F. C. Stockwell, W. B. Kouwenhoven, E. E. F. Creighton and Paul Agnew with closures by the authors. *The Character of the Thermal Storage Demand Meter*, by P. M. Lincoln. In this paper the author describes the meter and shows wherein it alone recognizes true heating effect that fixes size of equipment and therefore cost that should be assessed against customer. This paper was discussed by L. T. Robinson, Chester I. Hall, Frank V. Magalhaes, George L. Hoxie, W. H. Pratt, M. G. Lloyd, A. S. Albright, R. W. Atkinson, H. D. James and H. L. Wallau. The last paper of the session entitled *Measurement of Power Losses in Dielectrics of Three-Conductor High-Tension Cables*, by F. M. Farmer, describes the methods used for measuring the dielectric power losses in 10-foot samples of three-conductor cables with three-phase potential applied to cable. The following men took part in the discussion: H. W. Fisher, H. W. Atkinson, C. W. Davis, D. Du Bois, J. L. Harper, W. H. Cole, Philip Torchio, G. B. Shanklin, L. L. Elden, J. A. Walton, F. W. Peek, Jr., M. G. Lloyd, J. R. Craighead and C. A. Adams. Closure by author.

The third technical session on alternating-current commutator motors was called to order at 10:30 a. m. Saturday the sixteenth by Vice President Behrend, President Rice shortly thereafter taking the chair. The following papers were presented: *The Polyphase Shunt Motor*, by W. C. Altes, read by author. In this paper after discussing various forms of a-c. motors the author offers the induction motor with commutator on the primary side as best solution for machine-tool motors. *The Secomor*, by V. Karapetoff. Description of a mechanical device representing the vector diagram of voltages in a motor with any desired constant by means of which performance characteristics can be obtained. *Commutation in Alternating-Current Machinery*, by Marius A. C. Latour, read by C. O. Mailloux. In this paper the author introduces his theory that perfect commutation in a continuous-current motor depends substantially on the production of a mean resultant neutral field in the commutation region and shows that the production of a perfect revolving field in a polyphase commutator motor assists in insuring perfect commutation at exact synchronism. The three papers were discussed by the following men: B. A. Behrend, P. M. Lincoln, C. F. Scott, W. C. K. Altes, H. M. Hobart and W. B. Jackson with closures by W. C. Altes and V. Karapetoff.

On Thursday the 14th, the day preceding the formal opening of the convention, the folllowing committee meetings were held: Standards Committee at 10:30 a. m.; Meetings and Papers Committee at 1:00 p. m.; Finance Committee at 4:00 p. m.; Special Committee to Consider Location of Annual Convention at 4:45 p. m.; Board of Directors at 8:00 p. m. Subcommittee No. 20 (Circuit Breakers and Switches) of the Standards Committee met early in the day and later reported to the Standards Committee.

On Friday evening at 6:30 p. m. an informal dinner was held at the Cafe Boulevard. This was attended by about 225 members and guests. President Rice delivered an address in which he called attention to the urgent need in striving for an early and successful issue to the war of complete cooperation between government departments, industries, organizations and individuals. An abstract of President Rice's speech will be found elsewhere in this issue.

On conclusion of the dinner the members returned to Institute headquarters where an interesting lecture was delivered by Dr. A. C. Crehore on *Some Applications of Electromagnetic Theory to Matter*. Dr. Crehore's lecture will be published in a future issue of the PROCEEDINGS.

A. I. E. E. DIRECTORS' MEETING FEBRUARY 14, 1918

The regular monthly meeting of the Board of Directors of the Institute was held at Institute headquarters on Thursday evening, February 14, 1918, at 8:00 p. m.

There were present: President E. W. Rice, Jr., Schenectady, N. Y.; Vice-Presidents, B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y., A. S. McAllister, New York, John H. Finney, Washington, D. C.; Managers, John B. Taylor, Schenectady, N. Y., Harold Pender, Philadelphia, Pa., C. E. Skinner, Charles Robbins and Wilfred Sykes, Pittsburgh, Pa., N. A. Carle, Newark, N. J., Walter A. Hall, Lynn, Mass.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The Secretary announced the appointment by the President of the following members of the Tellers Committee: F. V. Magalhaes, A. V. Mershon, G. E. Schultz, L. Winter (one additional member to be appointed later).

The action of the Finance Committee in approving monthly bills amounting to $8,388.98 was ratified.

Upon the recommendation of the special committee which had been authorized at the January meeting of the Board to consider and report upon the desirability of holding an Annual Convention in June, 1918, it was decided to hold an Annual Convention this year in Atlantic City during the last week in June.

The report of the Board of Examiners of its meeting held on February 5 was accepted and the actions taken at that meeting were approved.

Upon the recommendation of the Board of Examiners the following action was taken upon pending applications: 48 Students were ordered enrolled, 143 Applicants were elected to the grade of Associate, 4 Applicants were reelected to the grade of Associate, 9 Applicants were elected to the grade of Member, 1 Applicant was transferred to the grade of Member, 1 Applicant was transferred to the grade of Fellow.

Secretary Pender of the Standards Committee stated that at the meeting of the committee held earlier during the day there had been some discussion regarding the name of the Code Committee of the Institute and that it appeared to those present that the name was somewhat ambiguous. The committee recommended that the Board of Directors adopt a name which would more clearly indicate the scope of the said committee. As the duties of the Code Committee as defined in the by-laws relate to the consideration and investigation of all matters relating to the formulation of rules for the protection of persons and property against fire and other hazards in connection with electrical installations and equipments, it was the opinion of the Board that a more definite name than the present one would be "Safety Code Committee." This meeting with unanimous approval, the Secretary was directed to submit to each member of the Board of Directors ten days in advance of the March meeting an amendment to Sections 22 and 29 of the by-laws providing for this change.

A considerable amount of other business was transacted, reference to which will be found in this and future issues of the PROCEEDINGS.

UNITED ENGINEERING SOCIETY
Extracts from President's Annual Report

For the year 1917 the noteworthy occurrences are the creation of Engineering Council, the completion of the addition to the Engineering Societies Building and the occupation by the American Society of Civil Engineers of the space thus provided for it, the addition of 67,000 volumes from the Civil Engineers Library to Engineering Societies Library; the election as Director of the Library of Harrison W. Craver, formerly of the Carnegie Library of Pittsburgh, and the election of Alfred Douglas Flinn to serve the United Engineering Society, the Engineering Foundation and Engineering Council jointly as their secretary, with offices in Engineering Societies Building, and to undertake the new duties January 1, 1918.

Engineering Council held its first meeting June 27, elected Ira N. Hollis chairman and Calvert Townley secretary, and during the year appointed the following committees: Executive, Rules, Finance, Public Affairs, American Engineering Service and War Committee of Technical Societies. Good work has been done, but the Council has not perfected its organization, and it was not until the close of the year that a definite financial arrangement was made; an appropriation of $16,000 was requested and granted for the term ending October 31, 1918, to be assessed equally upon the four Founder Societies.

In October, the three new stories of Engineering Societies Building were so far completed that the American Society of Civil Engineers could move into its new quarters, and were wholly completed before the end of the year. The total cost was $302,027.01, the increase over the estimate being caused by the War.

December 7, at a meeting in the Auditorium the three original Founder Societies and United Engineering Society tendered a welcome to American Society of Civil Engineers, which was referred to in the January PROCEEDINGS.

At the December 27 meeting of the Trustees United Engineering Society, the Building Committee, H. H. Barnes, Jr., chairman, E. G. Spilsbury, Charles Warren Hunt and Charles F. Rand, presented a final report, and upon its request, was discharged.

Completion of the first and major portion of the Catskill Mountain water supply system for New York City was celebrated by the United Engineering Society and the four founder societies by a special meeting held in the Auditorium, November 14, as previously reported in the December PROCEEDINGS.

During the year the by-laws of United Engineering Society were amended to create the office of Director of the Library and to provide for the creation of Engineering Council, the former amendment being made in February and the latter in June.

In November an appraisal of the building for fire insurance purposes was made by J. W. Clarke, Inc. The report of this appraisal placed the value of the portion of the building including the new stories, which should be insured at $1,030,000.

At this date the membership of the four Founder Societies is 33,100 and of the associated societies 25,154, so that a total of 58,254 engineers now have headquarters in the Engineering Societies Building.

The real estate now owned by United Engineering Society is valued at $1,947,171.16.

The income of the Society during 1917 was.....	$55,854.72
Expenditures totaled......	53,791.87
Gain for the year.........	2,062.85
Surplus at the close of 1916	6,053.25
Total...............	$8,116.10

Funds held by the United Engineering Society were of the following amounts at the end of the fiscal year 1917:

Library endowment fund	$102,559.70
Engineering Foundation fund	203,374.80
General Reserve fund	10,000.00
Depreciation and renewal fund	75,037.41
Surplus	8,116.01
Total	$399,088.10

In the report of the Treasurer are many interesting details about the Society's finances and in the report of the Library Board a full statement of its activities showing the importance of the work being done.

Calvin W. Rice resigned as Secretary of United Engineering Society to take effect at the end of December, and the Society is indebted to him for a year of gratuitous service.

To Joseph Struthers who has been Treasurer for nine years, and to the members of the Building Committee, especially its chairman, H. H. Barnes, Jr., the Trustees would express hearty thanks for valuable services.

The close of the year 1917 found the affairs of the United Engineering Society in a satisfactory condition.

ENGINEERING SOCIETIES LIBRARY
Report for 1917

The Library Board of the United Engineering Society has published its annual report for 1917 to the United Engineering Society and the Founder Societies. It may be briefly summarized as follows:

Service: The number of visitors was 11,371, an average of 40 per day. Of these 26 per cent or 2,983 visited the library during the evening after 6 p.m.

The service which the library gives to visitors is only one of its activities. It is estimated that at least 3,500 telephoned inquiries were answered during the year. Inquiries for searches numbered 551 and most of these required the making of bibliographies, translations or copying articles. Various departments and officials of the United States Government asked for assistance and effort was made to supply this and no charge was made.

The photostat installed in 1916 has proved its value and one photographer is scarcely able to handle orders received. The number of orders was 791, calling for 7,853 prints. Considerable work has been done for the Library in supplying missing pages by photoprints from other copies. Summary of work, as follows: Search Orders and Copying 492, Translations 59, Photoprint Orders 791. Total 1,342.

The Search Orders were divided as follows: Civil Engineering 77, Electrical Engineering 28, Mechanical Engineering 124, Mining and Metallurgy 121, Chemical 62, Miscellaneous 64, Copies 16. Total 492.

During the year the 59 translations amounted to 349,320 words, divided as follows: German 66.9 per cent, French 22.4 per cent, Italian 10.1 per cent, Bohemian 0.3 per cent, Russian, 0.2 per cent, Spanish 0.1 per cent.

Books: At the end of 1916 the Library contained 130,441 volumes and pamphlets. During 1917 there were added 2,337 pieces, divided as follows: Purchase 1,016, Exchange 160, Gift 1,041, Old Material 119, Maps 1. Books and Pamphlets withdrawn 77. Total Dec. 31, 1917, 132,701.

Arrangements were made for the printing in the publications of the Founder Societies of brief descriptive reviews of new books of interest to engineers and manufacturers, and leading publishers have furnished copies for this purpose. These books are added to Library. Owing to the war files of foreign publication, books and periodicals, are incomplete. A careful account of missing copies is kept and an immediate effort will be made to purchase missing numbers at the end of the war.

Binding: During the year 723 volumes of periodicals and 30 books were bound and 128 books and periodicals were rebound.

Gifts: Among the more important gifts were the book stacks presented by the American Society of Civil Engineers. Board of Water Supply of New York 195 volumes; Theodore N. Vail 505 volumes; Illuminating Engineering Society 80 volumes; N. E. L. A. 47 books and pamphlets; George Francis Whipple 55 volumes.

Ownership of the collections of the A. S. C. E. and the A. I. M. E. was formally tendered by these organizations to the United Engineering Society. These gifts will greatly simplify the work of administration.

Cataloging: Cataloging has progressed along two lines: new accessions and material already in catalog. The catalog lacks consistency and needs thorough revision. This will be begun at once. During the year there were catalogued 1,603 books, 306 pamphlets, 365 periodicals, and 116 bibliographies. Total 2,390 items.

Staff: Numerous changes in the staff occurred. Chief of these was the resignation on March 31, 1917 of Mr. William Cutler as Librarian. As his successor, the Society engaged, Harrison W. Craver, Librarian of the Carnegie Library of Pittsburgh. Mr. Craver began work April 1, 1917. Several other resignations deprived the Library of assistants who had been connected with it for a number of years.

Library Board: The Library Board held three regular meetings and one special one; while its Executive Committee held nine meetings. The death of Dr. E. F. Roeber deprived the Board of a valuable member. Mr. George C. Stone was elected by the A. I. M. E. to fill the vacancy.

Equipment: The work of equipping the fourteenth floor has practically been finished. An electric book lift, connecting the twelfth, thirteenth and fourteenth floors was built. The reading room was repainted.

Finance: The receipts and expenditures for 1917 as recorded by the Treasurer of the United Engineering Society are as follows:

Revenue	
Library Income Founders Contribution	$16,000.00
Library Endowment Income	5,760.42
Library Service Bureau Revenue	6,553.19
Library Sales and Income	29.40
Library Contribution U. E. S.	262.35
Total revenue	$28,605.36
Expenditures	
Library Books Purchased	$1,614.47
Library Binding Expense	1,393.35
Library Supplies & Miscellaneous Expense	1,299.89
Library Salaries (Except Service Bureau)	16,961.16
Library Service Bureau Salaries	5,322.00
Library Service Bureau Supplies	1,437.54
Moving Civil Engineers' Library	381.50
Development Committee Expenses	195.45
Total Expenditures	$28,605.36

WAR SERVICE EXCHANGE

The Adjutant General of the U. S. Army has established in connection with the work of the War Department the War Service Exchange, which will serve as a clearing house to which men desiring to serve the Government may apply for information as to openings in the War Department. The Exchange is also charged with finding experts for the special needs of the Staff Corps.

Members of the Institute who desire to enter Government service with the War Department may obtain information by addressing Mr. John J. Coss, Room 528, State, War and Navy Building, Washington, D. C.

A. I. E. E. HONOR ROLL

Members of the American Institute of Electrical Engineers in Army and Navy service with the United States and her Allies.

This list supplements those published in the three preceding numbers of the PROCEEDINGS and includes only those members who are in the armed forces and who have responded to the War Service card sent to the membership on Sept. 15, 1917, or have otherwise communicated with Institute headquarters.

Members in Army and Navy service who have not been listed are requested to furnish the Institute with their proper military designation.

ALGER, PHILIP L.
Second Lieutenant, Ordnance, R. C.
CARR, LUCIEN
First Lieutenant, 301st Stevedore Regiment.
CHEENY, RICHARD C.
Motor Section Instruction School
COLLINS, WALTER F.
37th Engineers.
CORBETT, L. J.
Captain, Engineer, R. C.
BRODIE, J. M.
Lieutenant, U. S. N. R. F.
DAVIS, W. R.
Ensign, U. S. N. R. F.
DE LA ROCHETTE, GEO.
Lieutenant, 17th Regiment, French Army.
DIEHL, GEO. S.
Lieutenant, junior grade, U. S. N. R. F.
DILLON, THEODORE H.
Lieut. Colonel, U. S. Army.
FRANKLIN, R. E.
Captain, Engineer, R. C.
FURUICHI, TATSUO
Engineer Lieut. Commander, Imperial Japanese Navy.
HAINES, WM. H.
Lieutenant, junior grade, U. S. N. R. F.
HANCOX, S. H.
Major, 2nd Field Co., Australian Engineers.
HEDGES, GEORGE L.
First Lieutenant, Ordnance, R. C.
HOLMAN, ARTHUR J.
Lieutenant, U. S. Army.
JONES, NELSON
Sapper, New Zealand Engineers, France.
KIMBALL, AUSTIN L.
Second Lieutenant, Ordnance, R. C.

KEY TO ABBREVIATIONS
N. R. F.—Naval Reserve Force.
R. C.—Reserve Corps.

KNOST, C. P.
First Lieutenant, Signal Corps.
LA MOTTE, W. R.
Lieutenant, junior grade, U. S. N. R. F.
LORCH, ALBERT
Electrician, first class, U. S. Navy.
LUNSFORD, R. L.
Aviation Section, Signal Corps
LUPINSKI, HUGO H.
Lieutenant, junior grade, U. S. N. R. F.
McFEDRIES, S. M.
Major, Ordnance, R. C.
MOORE, S. E.
37th Engineers.
MOULTROP, NORMAN I.
Sergeant, 498th Aero Squadron, Signal Corps
NYE, HORACE B.
377th Aero Squadron, Signal Corps.
OWEN, W. B., JR.
17 Co., 152 Depot Brigade, Ordnance Corps.
PAWSON, HERBERT E.
Lieutenant, 4th Pioneer Battalion, Canadian Expeditionary Force.
SACQUET, EMILE G.
First Lieutenant, 205th Infantry.
STEWART, A. B.
Captain, Royal Engineers, British Expeditionary Force.
STRIEBY, W. J.
First Lieutenant, Coast Artillery Corps.
WEBBER, LEON H.
Ensign, U. S. N. R. F.
WHITAKER, S. EDGAR
Major, Ordnance, R. C.
WILLIAMS, EDWIN P.
Aviation Section, Signal Corps.
YARDLEY, B. V. H.
Aviation Section, Signal Corps.

Total including previous lists, 721.

PROFESSIONAL CLASSES WAR RELIEF OF AMERICA

The purpose of the Professional Classes War Relief of America is to afford relief, not only to professional men whose incomes are cut off through war conditions, but also to the dependants of professional men who are killed or incapacitated in service.

The experience of England has shown that the professional classes are the first to suffer from the war, are the most continuous sufferers and the most difficult to relieve. Already certain professions in this country are feeling the effects of the war.

The organization of the Professional Classes War Relief of America has reached the point where they are prepared for the active work of relief of professional men who have enlisted, who are in the civil service, who are in civilian life, or of the families of such.

The main obstacle to such relief is the hesitancy of this class to make known their needs. Relief cases have to be sought out. Some cases have been found. Many more exist. All members of the A. I. E. E. are asked to cooperate by informing their brother professionals of this war relief, to be on the alert for all situations deserving relief, to make all possible inquiry as to such situations and to inform the organization, at 33 West 42nd St., New York City, immediately of all such cases as may come to their attention.

Particular emphasis should be laid on the fact that all applications for relief are held in strictest confidence and save to members of the investigating committee, are known only by number.

1918 YEAR BOOK

The Institute Year Book for 1918 will be ready for distribution early in March and may be obtained free of charge by any member upon application to the Secretary, 33 West 39th Street, New York, by mail or otherwise.

The book contains the constitution, by-laws, lists of officers and committees, alphabetical and geographical catalogues of the membership, and considerable other general information relating to the activities of the Institute.

EXTRACTS FROM THE ADDRESS OF PRESIDENT RICE AT THE MIDWINTER CONVENTION DINNER

There was never a time in the history of the world when work was more needed and when talking is only justified which may help forward the great work which is at hand. We all know what that great job is—the winning of the war. Everything else must wait and take a back seat until that job is done.

I wish first to say that we are fortunate in having in our President a spokesman who is able to state the ideals of the American people and their purpose in this great war in a manner so clear and so impressive as to perfectly satisfy and thrill every loyal American and he has so appealed to our Allies that he is now accepted as the leading spokesman for all on our side of the war. If our enemies were in a position to listen to an "appeal to reason" we could even hope that his messages would be accepted as the basis of peace. It is fortunate for the world's future that his messages contain no indication that we will be satisfied with an inconclusive peace and no matter how much we may hope that his messages may eventually break down the resistance of our enemy, through an appeal to reason, we are warned that it is vitally necessary to throw our full strength into winning the war, through the exertion of superior military and naval and industrial power.

I suppose we all think we know just how to win this war and we are all ready to give advice in private and some even in public. The newspapers, Congress, a long list of voluntary associations, engineering councils, labor leaders, business men, chambers of commerce, are all offering their advice to the administration.

The average citizen is mystified and wonders just what is the matter; he has been told that the greatest possible production, especially of war material, was vital to our success and this appealed to his common sense; but just as our manufacturers were getting up speed and working at high pressure they have been ordered to stop and to reduce pressure, as production is said to be ahead of the distributive facilities of the country. He has been told that the army organization had completely broken down, he has seen reports that the submarine menace had been mastered, only to note that the sinkings continue at an alarming rate; he was told that millions of tons of shipping were needed, and an organization was started to build these ships; he saw months of t me wasted in talk at a time when every day lost meant the loss of millions of dollars and of thousands of lives. After months of weary waiting the deadlock was broken and we got fairly launched upon a shipping program. We thought that we were running along fairly well when suddenly the entire country was stunned by the recent drastic order of the Fuel Administra or, closing many industries and stopping much of business life.

We were all greatly encouraged and thrilled during the early months of the war by the patriotic attitude of Congress which supported the administration in an unprecedented manner, without distinction of party.

The two great L berty Loans aggregating between five and six billion do-lars were voted and raised with the patriotic and enthusiastic support of all the country. A great scheme of taxation, more drastic and bearing more heavily upon the wealth of the country than anything known in our history has been passed and will be loyally supported.

The selective draft system was prepared and put into operation and accepted by the country in a truly magnificent manner. The Red Cross has been reorganized and an enormous amount raised by voluntary subscriptions. The Knights of Columbus are also doing magnificent work in a similar field.

In view of this record of accomplishment and our truly splendid start in the war, why has this feeling of nervousness come over the country; why has Congress suddenly changed its attitude of unquestioning support to one of investigation and criticism? Is it true that we are making a failure of the job?

It seems clear to me that we have not made a failure and that everything is moving along as well as we had a right to expect under all the circumstances. When we consider that less than a year ago our nation of a hundred million of people, entirely unprepared for war, was thrust into this greatest of enterprises, I think we have already accomplished wonders and that we should not be discouraged. A certain minimum of time is necessary to start, equip and get this nation into the war effectively. We should do everything possible to see that this minimum of time is not unduly prolonged. Business men and especially engineers and manufacturers must appreciate that our fundamental, and let us hope not fatal mistake, is that we waited until the war was thrust upon us before we started to get ready.

I think that a little reflection will make it clear that the mistakes that we have made are in the aggregate negligible compared with the overwhelming mistake of failure to prepare for the war during 1915 and 1916, that precious time has been lost forever and nothing can give us back the lost time. We must expend untold billions and make superhuman efforts but we must be patient and realize that inconsiderate haste is likely to result in a general retardation of our program.

This is a peoples' war—a war for democracy. To be successful the people must believe in the war and must work for the war. It would seem, therefore, that this fact being recognized, we should not attempt to handle the job on the basis that it is to be run exclusively by the party in power. In such an

emergency it does not seem probable that we can get best results by our customary majority or party government. All the people must be represented.

Would not confidence be greatly strengthened if those in political control would look beyond their party and take into the service of the nation its strongest men without reference to political affiliation?

The country is greatly encouraged at the large number of able men, prominent in business and other walks of life, who have volunteered for service in various departments of the Government and who have been accepted and set to work. This policy should be encouraged, as the more it is followed the better the country will be satisfied and the sooner we will win the war.

It is essential that the men who are charged with enormous responsibilities in our Governmental enterprises have the confidence of the country, as their orders, no matter how drastic or arbitrary or apparently unnecessary, should be followed with confidence. At the present time orders are patriotically obeyed, but with some misgiving. There is no lack of confidence in their good intentions and character but there is some questioning of their wisdom and practical experience.

The effectiveness and value of any organization is largely dependent upon the men who are on the job. The theoretically perfect system would break down and prove an utter failure if administered by men who are arbitrary, inexperienced or lacking in the spirit of cooperation. On the other hand a system that is apparently defective on paper can be made to operate with the greatest measure of practical success if the men filling positions of power and responsibility are men of vision, wisdom, practical experience, and full of the spirit of cooperation, men who take to "team-play" as naturally as a duck takes to water.

Every organization must demonstrate what it can do to help the country in its hour of need. Every organization, whether of capital, labor, manufacture or business, and every individual must be subjected to the test of whether it is doing its best and most effective work to win the war.

It is obvious that no single element by itself can win the war. Capital alone is helpless; labor alone is equally helpless. The Navy cannot win without the help of the Army, and both are helpless without ships. The sacrifices cannot be made by capital alone, or by labor alone, but must be distributed on a fair basis.

The test of patriotism will be the willingness to work, each in his own sphere, to the absolute limit. We need the maximum output of brains, labor and material; the country demands it, and the country will see that it is obtained. Any man or organization of men that stands in the way of the purpose which this country has set for itself will be eventually crushed.

I don't suppose that we can form any adequate idea of the stupendous task which the Government has undertaken, in its army, navy, shipbuilding, aircraft, and other programs. It simply staggers the imagination.

The personnel of the Governmental organization has undergone a rapid and tremendous expansion. The organization which was sufficient for our small peace program was, of course, absolutely unable to cope with the war program. After any organization has been brought into existence, time is required for the different units to learn their duties and particularly to learn how to cooperate with each other.

Time is also required for the country to transfer its industrial activities from commercial work to Governmental work. While this transfer must be made as rapidly as possible, even if great loss ensues, there is a limit to the rapidity with which this transfer can be effectively made.

It takes time for us to get over our ideas and practises, based upon our competitive conditions and education.

We are now to forget our education in competition, and think of nothing but cooperation; in other words, of what is best to increase the country's production as a whole, for that is vital in winning the war.

It is obvious that the Navy and Army cannot be built up without drawing upon the organization and facilities of the country and, therefore, our Government, as well as ourselves, must never forget that the preservation of the country's industries n the highest state of efficiency is a vital matter.

In order to avoid chaos, it is essential that Governmental departments should cooperate with each other and such cooperation is not merely a matter of organization but largely a matter of men or personnel. Cooperation to be effective must be wholehearted and instinctive.

I like the President's expression—"Spirit of accommodation" for that is an essential element of cooperation.

Now I wish to emphasize the fact that it takes time to produce really efficient cooperation. No new organization can possibly work as smoothly and effectively as one which has had time to become perfected.

Moreover, cooperation in Washington between departments will not enti ely settle the matter. We have a duty to perform. There must be cooperation among the industries. We must forget to compete and learn to cooperate with other units.

But this is not all, we must have cooperation between the Government and industries, and to be effective, this means that both must be a party to the cooperation. It cannot be a "lion and lamb" sort of affair. If the Governmental heads use their vast power arbitrarily and unwisely, they can easily cripple the industries of the country, and thus delay victory for years.

Take for example the matter of priority. This is merely one of the factors of production. All large industrial establishments hand'e such matters through a production department with a production manager at its head. If an inexperienced man were put in charge of the production of any establishment, he could, and probably would, with the best of intentions, reduce the productive efficiency of such an establishment by 50 per cent within a few weeks.

No man can be successful in an administrative posit on, large or small, who does not understand and practise cooperation as second nature; in fact, industrial organizations found that cooperation was so much more efficient and economical than destructive competition that they began to cooperate with other competing units, but were prevented by law.

The country has now found that these organizations are extremely useful under the present conditions and also that they are composed of individuals who have been trained in loyalty, and who are devoting themselves loyally and enthusiastically to the service of the country. Care must be taken not to disintegrate such organizations, as otherwise, great value will be lost to the country at this critical time.

I believe that the problems facing us will be successfully solved in time but we need more cooperation, more of the spirit of accommodation, all our patience and wisdom and above all, a willingne s to work to the lim t.

We must discipline ourselves until a shirker in any field of useful effort wi'l be regarded with the same contempt as a sh rker in the military service of the country, for there is no d fference, or if there is any difference, a sh rker behind the l nes is worse than one in the trenches.

Dated, February 15, 1918.

PUBLICATION OF TECHNICAL WORK OF THE JOINT COMMITTEE ON INDUCTIVE INTERFERENCE BY CALIFORNIA RAILROAD COMMISSION

The Joint Committee on Inductive Interference, organized in December, 1912, by the California Railroad Com-

mission and authorized to conduct an investigation of the problem of inductive interference to communication circuits by parallel power circuits has completed its work, after continuously investigating this subject for over five years, at a cost of over $100,000, borne jointly by the interested railroad, power, and communication companies and the California Railroad Commission.

The investigation has obtained results of great consequence to the electrical engineer in all branches of engineering, particularly to railways, power, telephone and telegraph companies, and to manufacturers of electrical apparatus. A knowledge of the work done and the results accomplished will prove indispensable also to such public utility commissions and other public authorities as have jurisdiction over the service of railways and power and communication companies.

Some of the general conclusions have been published by the technical press at different times during the progress of the investigation, but practically none of the technical data have thus far been made generally available. From time to time during the course of this work technical reports have been prepared which give the data obtained from the tests and the results and conclusions derived from both the tests and the theoretical studies. Thirty of these technical reports have been selected as being of such general interest and applicability as to warrant publication.

In addition to the technical reports the publication will contain final recommendations for rules for the prevention and mitigation of inductive interference and valuable historical matter concerning the investigation with general and technical discussions on the subject.

The book will have a complete index and contain approximately 1000 pages with over 400 drawings and 30 photographs.

The publication is contingent upon obtaining, in advance, a sufficient number of subscriptions to cover the actual cost of printing and binding, at not to exceed, and probably considerably less than, $10.00 per set (1 or 2 volumes).

If you are interested in this problem you will find these reports of great value and should enter your order at once. As the number of copies printed will be limited, only those subscribing in advance can be assured of receiving copies in the event the number of subscriptions justifies the publication. Those who place subscriptions will be advised as soon as possible whether the publication will be undertaken and the approximate cost per set. Do not send any money until you receive such notice.

A more detailed report on the work of the Joint Committee on Inductive Interference and on the scope and contents of the proposed book may be had upon request. Address all communications to California Railroad Commission, Attention Richard Sachse, Chief Engineer, 833 Market Street, San Francisco, Cal.

PAST SECTION MEETINGS

Boston.—February 5, 1918, Massachusetts Institute of Technology, Smith Hall. Paper: "The Present Trend of Technical Education," by Walter I. Slichter. Attendance 60.

Denver.—January 19, 1918, Denver Athletic Club. Paper: "The Manufacture of Military Explosives," by L. B. Skinner. Joint meeting with Colorado Association of members of A. S. C. E. Attendance 80.

Detroit-Ann Arbor.—January 11, 1918, University of Michigan, Engineering Building. Illustrated lecture by Mr. Luckiesh on "Lighting Art—Its Practise and Possibilities." Attendance 150.

Ft. Wayne.—January 29, 1918, Commercial Club. Address by Lieut. S. H. Cowing on "Radio Communication." Attendance 59.

Indianapolis-Lafayette.—January 25, 1918, Claypool Hotel, Indianapolis. Papers: (1) "Technical Features of

Radio Communication," by Col. Slaughter; (2) "Financial Problems of the Utility in War Time," by J. F. Gilchrist; (3) "Vocational and Industrial Education," by A. S. Hurrel. An illustrated lecture was given by Mr. J. E. Freeman on "Concrete Ships and Barges." The evening session was devoted to an address by Mr. Will H. Hayes, on "The Engineer and the State Council of Defense," followed by a motion picture entitled "The King of the Rails." Joint meeting with Indiana Engineering Society, the A. S. M. E., and the Indianapolis Engineers Club. Attendance 117.

Los Angeles.—January 15, 1918. Illustrated address by Mr. H. C. Gardett on "The Hydroelectric Development of the City of Los Angeles." Attendance 40.

Lynn.—February 2, 1918. New Thomson Research Laboratory. Addresses were delivered as follows: (1) "Electrification and Fuel Economy," by E. W. Rice, Jr., President A. I. E. E.; (2) "Responsibility and National Affairs," by Lieut. Governor Calvin Coolidge of Massachusetts; (3) "Loyalty," by Mayor Creamer of Lynn; (4) "The Experiences of My Battery on the Western Front," by Capt. P. F. Daw, 2nd Canadian Field Artillery; (5) "Reminiscences," by Prof. Elihu Thomson. Attendance 649.

Madison.—January 17, 1918, University of Wisconsin, Electrical Laboratory. Papers: (1) "Instrument Transformers—A Discussion of Field Testing Methods," by F. A. Kartak; (2) "Field Experiences and Developments in Testing," by H. M. Crothers. Attendance 33.

Minnesota.—January 30, 1918. Address by Mr. R. A. Lunquist, Commercial Agent of U. S. Dept. of Commerce. Attendance 29.

Panama.—January 20, 1918, Balboa Heights, C. Z. Paper: "Faults in Submarine Cables and Location of Same," by Otto Hecksher. Attendance 25.

Pittsburgh.—January 19, 1918, Hotel Chatham. Papers: (1) "Methods of Power Factor Correction," by R. A. McCarty; (2) "Generation, Distribution and Consumption of Power," by B. W. Gilson and B. A. Cornwell. Joint meeting with Association of Iron and Steel Elec. Engrs. Attendance 300.

Pittsfield.—January 17, 1918, Hotel Wendell. Illustrated lecture by Mr. Sydney B. Paine on "Motor Drive in Textile Mills." Attendance 85.

January 31, 1918, Masonic Temple. Illustrated lecture by Mr. W. D'A. Ryan on "Illumination of the Panama-Pacific International Exposition." Attendance 550.

San Francisco.—January 25, 1918, Engineers Club. Paper: "Corona Tests at High Altitude," by B. F. Jacobsen. Attendance 80.

Schenectady.—January 24, 1918, Edison Club Hall. Paper: "Advantages of High Steam Pressure and Superheat as Effecting Steam Plant Efficiency," by Eskil Berg. The paper was illustrated by lantern slides. Attendance 182.

February 1, 1918, Edison Club Hall. Paper: "Standardized Flexible Distributing Systems in Industrial Plants," by Basset Jones. The paper was illustrated by lantern slides. Attendance 143.

Seattle.—January 15, 1918, Arctic Building. Annual reports of officers. Paper: "Powdered Coal," by W. J. Santmyer. Attendance 25.

Spokane.—January 18, 1918, Chamber of Commerce. Addresses as follows: (1) "Ethics of Central Station Buying," by V. G. Shinkle; (2) "Handling and Accounting of Materials through General Stores," by H. F. Gehring; (3) "Selling and Installing Isolated Plants," by W. L. Kimmel; (4) "Street Railway Accounting," by P. Hayward; (5) "High Spots of an Annual Audit," by H. E. Kaesemeyer. Attendance 45.

Toledo.—January 25, Toledo Builders Exchange. Election of officers as follows: chairman, Wm. A. Hill;

vice-chairman, A. W. Little; secretary-treasurer, Max Neuber. Attendance 18.

Toronto.—January 18, 1918, Engineers Club. Paper: "The Commercial Applications of Synchronous Motors," by M. J. McHenry. Attendance 60.

February 1, 1918, Engineers Club. Illustrated lecture by Professor A. P. Coleman on "A Scientist in South America." Attendance 55.

Washington.—January 18, 1918, Cosmos Club. Paper: "The Technical Story of Frequency," by B. G. Lamme. Attendance 112.

PAST BRANCH MEETINGS

Bucknell University.—January 31, 1918. Paper: "Steel Mill Motor Control," by Geo. A. Irland. Attendance 12.

Clarkson College of Technology.—February 6, 1918. Paper: "Short Cuts and Checks in Computation," by J. P. Brooks. Attendance 16.

Colorado State Agricultural College.—February 4, 1918, Main Building. Four reel motion picture entitled "Electrification of Steam Railroads." Attendance 12.

University of Colorado.—February 7, 1918, Hale Science Building. Paper: "The Manufacture of Military Explosives," by Louis B. Skinner. Attendance 155.

University of Iowa.—December 11, 1917, Physics Hall. Illustrated lecture on "Modern Methods of Manufacturing Incandescent Lamps."

University of Missouri.—January 5, 1918, Y. M. C. A. Building. Paper: "Mine Hoists," by J. Godwin. Attendance 22.

February 4, 1918, Y. M. C. A. Building. Paper: "Electrolysis of Return Circuit and Some Remedies," by H. B. Stone. Attendance 15.

North Carolina College of Agricultural and Mechanical Arts.—January 15, 1918. Lecture by Messrs. J. A. Northcott and W. D. Johnson on "Electrical Signal Work in the U. S. Army." Election of officers as follows: chairman, F. N. Bell; vice-chairman, B. B. Brown; secretary-treasurer, L. C. Flournoy.

University of North Dakota.—December 6, 1917. Paper: "The Sixty-Cycle Rotary Converter," by R. K. Culbertson.

Ohio Northern University.—January 23, 1918. Addresses as follows: (1) "Water-Power," by R. M. Bayle; (2) "The Essex Power Station," by H. D. Ronk. Attendance 32.

Ohio State University.—January 18, 1918, University Chapel. Motion pictures of the Life of Edison by courtesy of General Electric Company. Attendance 100.

University of Oklahoma.—January 15, 1918, Engineering Building. Papers: (1) "The Electron," by F. G. Tappan; (2) "The Interborough Rapid Transit Central Station," by J. H. Felgar; (3) "Large Types of Steam Boilers," by G. B. Helmrich; (4) "Technical Story of the Frequencies," by B. G. Lamme. Election of officers as follows: chairman, C. T. Hughes; vice-chairman, J. H. Phillips. Joint meeting with local branch of A. S. M. E.

Pennsylvania State College.—January 18, 1918, Engineering Club Room. Address by Dr. Woodruff on "Magnetic Clutches for Automobiles." Election of officers as follows: president, P. J. F. Derr; secretary, J. F. Kray. Attendance 45.

Purdue University.—January 23, 1918, Electrical Engineering Building. Illustrated address by Mr. M. K. Zinn on "The Fundamental Principles of Wireless Telegraph Circuits." Attendance 58.

Agricultural and Mechanical College of Texas.—January 23, 1918, Auditorium. Motion pictures, "The Life of Thomas A. Edison," by courtesy of General Electric Company. Attendance 300.

Throop College of Technology.—February 1, 1918. Illustrated address by Prof. W. H. Adams on "Engineering in China." Attendance 30.

Virginia Polytechnic Institute.—January 18, 1918, Science Hall. Paper:

"The Reclamation of Potash from Stack Gases," by Professor Pritchard. Attendance 19.

University of Virginia.—January 23, 1918, Electrical Laboratory. Papers: (1) "Portable Army X-Ray Sets," by Henry L. Painter; (2) "Electric Service in Shipbuilding," by Harrold L. McCarter; (3) "Engineering and War—Synonymous," by W. S. Rodman. Election of officers as follows: chairman, John M. Nalle. Attendance 16.

State College of Washington.—January 25, 1918. Election of officers as follows: chairman, B. Benz; vice-chairman, J. L. Williams; secretary, C. E. Guse; treasurer, D. Russel; reporter, H. R. Zeuner. Attendance 14.

West Virginia University.—January 25, 1918, Engineering Assembly Room. Election of officers as follows: chairman, H. B. Duling; vice-chairman, J. M. Connor; treasurer, E. M. Curtiss; secretary, F. L. Davis. Attendance 21.

Yale University.—January 18, 1918. Illustrated lecture by Mr. T. McL. Harding on "Electrification of Freight Terminals." Attendance 50.

MEMBERS ELECTED FEBRUARY 14, 1918

BECKER, ALFONSE N., Erecting Engineer, Allis-Chalmers Mfg. Co.; res., 1367 Holton St., Milwaukee, Wis.

BROUGHALL, GEORGE, Chief Tech. Asst., Elec. Engr's. Dept., London & Northwestern Ry., Euston Sta., London, Eng.

ELLIS, EDWARD ROYSE, Asst. Manager, Westinghouse Electric Export Co., 165 Broadway, New York, N. Y.; res., 10 Curtis Place, Maplewood, N. J.

JACOBS, ALBERT MICHAEL, Electrical Engineer, Chile Exploration Co., 120 Broadway, New York, N. Y.; res., East Orange, N. J.

KENNEDY, TERRENCE O., Gen. Supt., Denver Gas & Electric Light Co.; res., 821 Fillmore, Denver, Colo.

SIBLEY, EDGAR DOW, Supt. of Operation, Metropolitan Edison Co., Reading; res., 235 Reading Ave., W. Reading, Pa.

SMITH, HARRY J., Manager, East Section, National Filling Factory No. 7, Hayes, Middlesex, England.

TEEGARDEN, CHESTER H., Captain, Signal Corps, U. S. R.; res., 2918 24th St. N. E., Washington, D. C.

WARD, JAMES AUSTIN, General Manager, Natrona County Electric Co.; res., 506 So. Durbin St., Casper, Wyoming.

ASSOCIATES ELECTED FEBRUARY 14, 1918

ALLAMONG, JOHN W., Construction Engineer, Westinghouse Elec. & Mfg. Co., Philadelphia; res., Hamburg, Pa.

*ALLEN, GEORGE YOUNG, Radio Division, Bureau of Steam Engineering, Navy Dept.; res., 1915 14th St. N. W., Washington, D. C.

APPLEGATE, RAY HUGH, Electrode Sales Engineer, National Carbon Co.; res., 15601 Lake Shore Blvd., Cleveland, Ohio.

ARMSTRONG, RUSSEL MCKAY, Telephone Engineering, Pacific Tel. & Tel. Co., 1103 Telephone Bldg.; res., 344 Monroe St., Portland, Ore.

*BALMFORD, JOSEPH ARTHUR, Inspector, Crocker-Wheeler Co., Ampere, N. J. res., 509 W. 146th St., New York, N. Y.

BASS, LELAND BENNETT, Instructor, U. S. School Military Aeronautics, Georgia School of Technology; res., 249 N. Moreland Ave., Atlanta, Ga.

BAUSCHSPIES, FREDERICK R., Special Electrician, Wm. Cracp & Sons Ship & Engine Bldg. Co.; res., 146 W. Luray St., Germantown, Peiladelphia, Pa.

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*BENNETT, CHARLES BIGELOW, Electrical Engineer, Wagner Electric Mfg. Co.; res., 6146 Suburban Ave., St. Louis, Mo.

BENNISON, LIONEL CHARLES, Shift Engineer, Hydro-Electric Power House, Waddamana, Tasmania, Australasia.

BENSON, ROBERT JOHN, Maintenance Engineer, Wagner Electric Mfg. Co., 6400 Plymouth Ave.; res., 5963 Maple Ave., St. Louis, Mo.

*BENZ, WILLIAM KARL, Electrical Course, Coast Artillery School, Ft. Monroe, Va.; res., 167 Division St., Greensburg, Pa.

*BERGSTRESSER, HAROLD FREDERICK, Private Signal Corps, U. S. A.; res., 328 Main St., Emaus, Pa.

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CONKLIN, ALBERT B. W., Testing of Controlling Devices, Cutler-Hammer Mfg. Co.; res., 428 4th Ave., Milwaukee, Wis.

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COX, HOLLAND EUGENE, Engineering Dept., B. R. L. & P. Co.; res., 1322 Cullom St., Birmingham, Ala.

CUNHA, MANUEL RAUL DE FIGUEIREDO, Research Dept., British Westinghouse Elec. & Mfg. Co., Trafford Park, Manchester, Eng.

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*DELLINGER, LLEWELLYN MILLER, High Tension Inspector, Central District Tel. Co.; res., 46 Clifton Blvd., Carrick Boro, Pittsburgh, Pa.

*DIBLE, HARVEY JACKSON, Engineering Dept., C. D. Tel. Co., 416 Seventh Ave., Pittsburgh; res., 730 First St., Verona, Pa.

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*DUNCAN, J. RAY, Assistant Professor of Electrical Engineering, University of Kentucky, Lexington, Ky.

EISMANN, CARL ERNEST, Designing Electrical Engineer, General Electric Co.; res., 23 Haigh Ave., Schenectady, N. Y.

*FELKER, PAUL H., Inspector, Engineering Material, U. S. Navy, Highland Bldg., Pittsburgh, Pa.; res., 6949 Mitchell Ave., St. Louis, Mo.

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*FOSKETT, EARLE LAKE, JR., Electrical Engineer, Public Service Comm., 1st Dist, New York; res., 77 Jefferson Ave., Brooklyn, N. Y.

*GARVEY, WALTER SCOTT, Sales Engineer, Westinghouse Elec. & Mfg. Co., 511 Alworth Bldg.; res., 1714 London Road, Duluth, Minn.

GEORGE, LEROY E., Foreman of Electric Line Dept., Du Pont Powder Co.; res., 505 N. 6th St., Hopewell, Va.

GIVEN, ELTON BARNUM, Chief Engineer, "Clark's Hotel," 577 Washington St., Boston; res., 2 Metcalf St., Medford, Mass.

GLANCY, ROBERT CLIFFORD, Construction Engineer, Bell Tel. Co. of Pa., 1230 Arch St., Philadelphia; res., Narberth, Pa.

*GOLDSTENE, ALFRED B., Manager, Charles A. Borne Co., 35-37 Wooster St.; res., 868 E. 163rd St., New York, N. Y.

*GRAHAM, ROBERT WILLIAM, Lieut., (junior grade), U. S. N. R. F., Reserve Officers Quarters "B," Annapolis, Md.; res., Carrington, N. Dakota.

GRAMM, JOHN R., Electrical Engineering Student, Bliss Electrical School, Takoma Park, Washington, D. C.; res., 88 Woodlawn Ave., Albany, N. Y.

HAMDI, ABDULLAH FEYZI, Laboratory Asst.. Test Dept., N. Y. Edison Co.; res., 627 W. 138th St., New York, N. Y.

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HENDRICKS, LAIRD WOODRUFF, Supt., Electric Shops, N. Y., N. H. & H. R. R. Co., Van Nest, N. Y.; res., Glennbrook, Conn.

HIGHTOWER, CHARLES ROBERT, Engineer, Operating Dept., Public Service Elec. Co.; res., 137 E. Hanover St., Trenton, N. J.

INNES, FRANK R., Asst. to Distribution Engineer, The Detroit Edison Co.; res., 28 Woodward Terrace, Detroit, Mich.

*JACOBY, ARTHUR BERTSCH, Draftsman, American Rolling Mill Co.; res., 625 Garfield Ave., Middletown, Ohio.

*JOHNSON, ELMER W., Chief Draftsman, Minneapolis General Electric Co.; res., 1111 4th St. S. E., Minneapolis, Minn.

KEPHART, SAMUEL WEISEL, Electrical Engineer, 263 Divisadero St., San Francisco, Cal.

KIDD, GEORGE E., Engineer & Asst. Supt. of Power, N. N. & H. Ry. G. & E. Co., Hampton; res., 130 35th St., Newport News, Va.

KLAUDER, LOUIS T., Construction Engineer, Philadelphia Rapid Transit Co., Philadelphia, Pa.; res., 830 Park Avenue, Collingswood, N. J.

KLEBERG, ALFRED LEON, Division Manager, Texas Gas & Electric Co., Kingsville, Texas.

KNAPP, P. R., Junior Engineer, Toledo Railways & Light Co.; res., 2117 Putnam St., Toledo, Ohio.

KNOX, RUSSELL WILSON, Substation Operator, Homestake Mining Co.; res., Clark Flats, So. Gold St., Lead, So. Dakota.

KUHLMANN, HANS H., Electric Machinery Co.; res., 705 7th St. S. E., Minneapolis, Minn.

LANDIS, KENNETH, Sales Engineer, Crocker-Wheeler Co., Old Colony Bldg.; res., 5428 Woodlawn Ave., Chicago, Ill.

LEACH, ARTHUR WILLIS, Chief Designer, Electrical Engineer, Western Electric Co., Hawthorne Plant; res., 3424 So. Harold Ave., Berwyn, Ill.

LEACH, HARVEY BELMONT, Test Dept., New York Edison Co., 92 Vandam St., New York; res., 447 State St., Brooklyn, N. Y.

*LEWISON, E. K., Assistant Electrical Engineer, Timken Roller Bearing Co.; res., Y. M. C. A., Canton, Ohio.

*LEONARD, HAROLD C., Electrical Engineer, Submarine Boat Corp., Port Newark Terminal; res., 20 Pennington St., Newark, N. J.

*LINDSEY, GEORGE HEATH, District Sales Manager, Century Electric Co., 525 Granite Bldg., Rochester, N. Y.

LOGAN, HARRY SEYMORE, Electrician; res., 837 W. Granite St., Butte, Mont.

*LUNDGREN, ARTHUR NATHANIEL, Electrical Engineer, Plant Dept., Western Electric Co., Hawthorne Station; res., 4864 St. Paul Ave., Chicago, Ill.

LUNSFORD, ROBERT LEWIS, Experimental Laboratory, Crocker-Wheeler Co., Ampere; res., 173 No. 12th St., Newark, N. J.

LYNES, GORHAM MALTBIE, Lieut. (junior grade,) U. S. N. R. F., U .S. Naval Academy, Annapolis, Md.; res., 200 Hicks St., Brooklyn, N. Y.

*MACCALLA, POWELL STACKHOUSE, Private in Headquarters Co. 304 Engineers, Camp Meade, Md.; res., 3919 Locust St., Philadelphia, Pa.

MACGILLIVRAY,ROSWELL HENRY,Salesman, Electric Merchandise, Cutler-Hammer Mfg. Co., New York; res., 93 N. 13th St., Flushing, N. Y.

MANECKJ, JAHANJIR B., Assistant Electrical Shift Engineer, Power House, Tata Hydro-Electric Power Supply Co., Khopoli, India.

MANN, HAROLD A., Foreman, Meter Dept., Electric Lt. & Pr. Co. of Abington & Rockland, N. Abington; res., 23 Plain St., Rockland, Mass.

MANSFIELD, PERCY BLINN, Tester, General Electric Company; res., 339 West 4th St., Erie, Pa.

*MAURER, FRANK CLARENCE, Engineer, E. W. Clark Management Corp.; res., 240 E. 19th Ave., Columbus, Ohio.

McDOWELL, I. W., Electrical Engineer, Western Electric Co., Inc., Hawthorne Station; res., 324 S. Sacramento Blvd., Chicago, Ill.

McNALLY, JOSEPH WASHINGTON, Foreman, Van Wagoner & Linn Co., 1133 Broadway, New York; res., 167 Ross St., Brooklyn, N. Y.

MERRILL, GLENN WASON, Foreman, Electrical Construction, James Wilkinson Co., 92 Arch St., Boston; res., 60 Prescott St., Reading, Mass.

*MILLER, FRANK HERBERT, Construction Foreman, Keystone Electric Co.; res., 74 W. Beau St., Washington, Pa.

MILLER, LLOYD E., Chief Tester, Reliance Electric & Engineering Co.; res., 1245 E. 145th St., E. Cleveland, Ohio.

MOAS, BALTHASAR, JR., Electrical Engineer, Kelvin Engineering Co., Obrapia 25; res., San Lazaro 188, Havana, Cuba.

MORELAND, ELDON WRIGHT, Appraisal Engineer, Portland Railway, Light & Power Co., 507 Electric Bldg., Portland, Ore.

NAFZGER, EDWIN, Draftsman, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 515 Jeanette St., Wilkinsburg, Pa.

NAGASHIO, HIROSHI, Chief Electrician, Mine Dept., Mitsu-Bishi Co., Maru-no-uchi; res., 50 Sendagi-cho, Hongo, Tokyo, Japan.

NOMOF, MAX, JR., Electrical Engineer, Public Service Commission, 1st District; res., 319 E. 13th St., New York, N. Y.

O'CONNOR, ALBERT, In charge Switchboard Dept., Westinghouse Elec. & Mfg. Co., Boston; res., 5 Bracmore Road, Brookline, Mass.

OLSON, SIGFRID A., Chief Draftsman, Chile Exploration Co., 120 Broadway, New York; res., 68 W. Seaman Ave., Freeport, N. Y.

PALMER, JAMES BRIAN, Assistant Engineer, Transformer Dept., British Westinghouse Elec. & Mfg. Co. Ltd.; res., 26 Ryecroft Rd., Stratford, Manchester, England.

*PARSONS, GEORGE MILTON, Asst. Distribution Engineer, Syracuse Lighting Co., 431 Fulton St.; res., 425 Waverly Ave., Syracuse, N. Y.

*PARSONS, OLIN D., American Can Company, 120 Broadway, New York; res., 269 McLean Ave., Yonkers, N. Y.

*PENN, JOHN GEORGE, Toll Line Engineer, Michigan State Tel. Co.; res., 1221 Waterloo St., Detroit, Michigan.

PERRY, EMIL BATES, Ensign, U. S. N. R. F., Public Works Dept., Navy Yard, Boston; res., 689 Columbia Road, Dorchester, Mass.

POLING, CURTIS EUGENE, Sub-Inspector (Electrical), Bureau of Steam Engineering, U. S. Navy, 809 Gwynne Bldg., Cincinnati, Ohio.

PRINCE, WILLIAM EDWARD, Electrical Engineering Dept., Boston Elevated Railway, Boston; res., 71 Sycamore St., Winter Hill, Mass.

*RATHBUN, HARRY JOHN, Electrical Engineer, Federal Telegraph Co., Palo Alto; res., 200 Leland Ave., Mayfield, Cal.

*RAUBE, WILLIAM CARL, Electrical Engineer, General Electric Co.; res., 145 Nott Terrace, Schenectady, N. Y.

RAYNER DAVID DYSON, Engineer & Designer, The Electric Construction Co. Ltd., Bushbury; res., "Oakside", Oxley Bank, Wolverhampton, Eng.

*REHMAN, NORMAN J., Cadet Engineer, Public Service Electric Co.; res., 135 Rehner Ave., Newark, N. J.

ROBLEY, R. R., Operating Engineer, Portland Ry., Lt. & Pr. Co.; res., 1276 E. Morrison St., Portland, Ore.

SAMUEL, EDWARD, Asst. to Supt. of Line Construction, Wilmington & Philadelphia Traction Co.; res., 2604 Harrison St., Wilmington, Del.

SAWYER, WILLIAM BREWSTER, JR., Sales Engineer, U. S. Steel Products Co., San Francisco; res., 1415 Morton St., Alameda, Cal.

SCHNEIDER, FRANCIS JOSEPH, Asst. Switchboard Operator, Philadelphia Electric Co.; res., 2045 So. 19th St., Philadelphia, Pa.

*SCHOTT, ROBERT CARL, Switchboard Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., 313 Penwood Ave., Wilkinsburg, Pa.

*SCHROEDER, CARL WILLIAM, Draftsman, American Arch Co., 30 Church St., New York, N. Y.; res., Hotel Manhattan, Paterson, N. J.

SCHROETER, JOHN PAUL, Instructor, Head of Extension Div., School of Engg. of Milwaukee; res., 737 Mr-ashall St., Milwaukee, Wi.s

*SHUGREN, MAURICE ULYSSES, Cadet Engineer, Denver Gas & Electric Light Co.; res., 4521 Jason St., Denver, Colo.

SILBERZVEIG, LEON, Electrical Engineer, Riegos y Fuerza del Ebro, S. A.; res., Paseo de Gracia 79, Barcelona, Spain.

SINCLAIR, LOUIS BROWNE, Electrical Draftsman, Emergency Fleet Corp., 841 Munsey Bldg., Washington, D. C.

*SLATER, HAROLD CHARLES, Engineering Dept., Wagner Electric Mfg. Co.; res., 754 Hamilton Ave., St. Louis, Mo.

SMITH, WALTER CURTIS, Asst. Prof. of Electrical Engineering, A. & M. College of Texas, College Station; res., Bryan, Texas.

*STEHMAN, EDWARD HENRY, Assistant Engineer to H. O. Swoboda, 406 Empire Bldg., Pittsburgh; res., 111 Crafton Ave., Crafton Heights, Pa.

STEIN, S. MELVILLE, Foreman, Standardizing Laboratory, New York Edison Co.; res., 521 W. 112th St., New York, N. Y.

STEVENSON, O. H., Power Plant Operator, Pacific Power & Light Co., Naches, Wash.

*STOTZ, JOHN KENNING, Captain, Infantry, U. S. R.; res., 51 Afton Ave., Crafton, Pa.

STRAUS, HENRY LOBE, Engineer, Cutler-Hammer Mfg. Co., 50 Church St.; res., 43 West 58th Street, New York, N. Y.

STYER, CHARLES A., Instructor in Electrical Engineering, Physics & Chemistry, U. S. Naval Academy; res., 210 Prince George St., Annapolis, Md.

SUNDBERG, EMANUEL WILLIAM, Designer, Wagner Electric Mfg. Co.; res., 6912 Page Ave., St. Louis, Mo.

TALLMADGE, HIRAM ARTHUR, Asst. to Supt. of Power, Minnesota & Ontario Power Co.; res., 319 Third St., International Falls, Minn.

*THATCHER, GEORGE RICHARD, Special Electrician, Electrical Dept., Illinois Steel Co., So. Chicago, Ill.

THOMPSON, JOSEPH GILMORE, Estimator, United Electric Construction Co., 1727 Sansom St.; res., 3107 N. 24th St., Philadelphia, Pa.

TINKEY, OTTO GEORGE, Electrician, Ideal Electric Co.; res., 502 S. Neil St., Champaign, Ill.

TOMANN, ORVILLE RAYMOND, Electrical Engineer, Radio Co., 109th Field Signal Battalion, Camp Cody, New Mexico.

WALKER, FRANCIS JOHN, Salesman, Electric Specialties, Cutler-Hammer Mfg. Co., 50 Church St., New York, N. Y.

*WEBBER, LEWIS G., Electrical Engineer, Monks & Johnson, 78 Devonshire St., Boston; res., Bedford, Mass.

*WEILBACHER, WILLIAM CARL, Interior Construction Dept., Detroit Edison Co.; res., 121 E. Grand Blvd., Detroit, Mich.

WEISS, TOBIAS, District Sales Manager, Ideal Electric & Mfg. Co.; res., 1008 Newhall St., Milwaukee, Wis.

*WELLS, GRANT ROBERT, Instructor in Elec. Engg., Univ. of Wisconsin; res., 405 N. Henry St., Madison, Wis.

WENZEL, ADOLPHE HELCK, Elec. Engr., D. C. & Wm. B. Jackson, 248 Boylston St.; res., 491 Commonwealth Ave., Boston, Mass.

*WHITEMAN, CARL A., Transformer Commercial Dept., General Electric Co.; res., 192 1st St., Pittsfield, Mass.

*WICKERSHEIM, LYLE WILLIAM, Research Dept., Western Electric Co., 463 West St., New York, N. Y.; res., E.Orange, N. J.

WIECKS, JACK F., Electrician, Washington Water Power Co.; res., N. 221½ Post St., Spokane, Wash.

*WIESEMAN, ROBERT WILLIAM, A. C. Engineering Dept., General Electric Co.; res., 705 South Ave., Schenectady, N. Y.

WILTBERGER, CONSTANT F., Engineering Dept., Lewis & Roth Co., 1012 Liberty Bldg.; res., 2049 N. Park Ave., Philadelphia, Pa.

*WOOD, EDWIN EUGENE, Draftsman & Inspector, Mech. Engg. Dept., N. Y. C. R. R.; res., 1751 Van Buren St., New York, N. Y.

*WOOLFOLK, ROPER B., Chief Tester, New York Edison Co., 92 Vandam St.; res., 44 West 92nd St., New York, N. Y.

ZAJAC, ADAM, Test Dept., General Electric Co.; res., 130 E. 9th St., Erie, Pa.

ZELINGER, WALTER, Order Dept., General Electric Co., 120 Broadway, New York; res., 574 East 26th St., Brooklyn, N. Y.

ZIMMERMAN, MICHAEL V., Electrical Draftsman, Tennessee Coal, Iron & R. R. Co.; res., East Thomas Station, Birmingham, Ala.

ZUEHEKE, ERWIN FREDERICK, Gen. Supt., Chief & Electrical Engineer, Escanaba Traction Co.; res., 209 So. Oak St., Escanaba, Mich.

*Former enrolled students.

Total 143.

ASSOCIATES RE-ELECTED FEBRUARY 14, 1918

McGOVERN, MAURICE TERRANCE, Power & Mining Engg. Dept., General Electric Co.; res., 32 Swan St., Schenectady, N. Y.

STAGE, ROY C., Sales Engineer, Calebaugh Self-Lubricating Carbon Co., Philadelphia, Pa.; res., Mizpah Hotel, Syracuse, N. Y.

THOMPSON, M. T., Investigating Electric Utilities Companies, Electric Bond & Share Co., New York, N. Y.; res., 35 Woodside Ave., Ridgewood, N. J.

WINDER, CLARENCE A., Manager, Niagara Falls Office, General Electric Co.; res., 29 Roebling Place, Niagara Falls, N. Y.

TENNANT, JOSEPH ALLAN, Consulting Engineer, Tennant-Lovegrove Co., Houston, Tex.

WALDEN, ALBERT E., Supt. & Chief Engineer, Baltimore Co. Water & Electric Co.; member of firm of Wehr & Walden, Baltimore, Md.

WOODWARD, MARK RITTENHOUSE, Lehigh Portland Cement Co., Allentown, Pa.

TRANSFERRED TO THE GRADE OF FELLOW FEBRUARY 14, 1918

CARPENTER, HUBERT VINTON, Dean of Mechanic Arts and Engineering, State College of Washington, Pullman, Wash.

EMBREE, CLAYTON J., Office Engineer, Panama Canal, Balboa Heights, C. Z.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on February 19, 1918, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Member

BLACK, N. HENRY, Master of Science, Roxbury Latin School, Boston, Mass.

GUMAER, PERCY W., Chief Engineer, Elektriska Aktiebolaget Volta, Stockholm, Sweden

HALL, GAYLORD C., Electrical Engineer, Interborough Rapid Transit Co., New York, N. Y.

HOWE, EDWARD S., Electrical Engineer, Cia, Antiquena de Instalaciones Electricas, Medellin, Colombia, S. A.

LEWIS ARTHUR PARKER, Cohasset, Mass.

LEWIS, GEORGE EVELINE, Supt. of Hydraulic Plants, Detroit Edison Co., Ann Arbor, Mich.

SCHURIG, O. ROBERT, Consulting Engineering Laboratory, General Electric Co., Schenectady, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before March 31, 1918.

Affel, H. A., New York, N. Y.
Aldridge, T. H. U., (Fellow), Shanghai, China
Allen, R. W., Milwaukee, Wis.
Ashauer, F. H., West Allis, Wis.
Ashe, M. J., New York, N. Y.
Austin, L. F., Spokane, Wash.
Baird, J. E., New York, N. Y.
Barnes, M. S., San Francisco, Cal.
Bason, G. O., New York, N. Y.
Behringer, C. R., Schenectady, N. Y.
Benham, H. M., Newark, N. J.
Bergman, G. E., Seattle, Wash.
Bergstein, I., Boston, Mass.
Bolibaugh, C. G., E. Pittsburgh, Pa.
Bonnett, L. B., Schenectady, N. Y.
Bonomi, F. A., New York, N. Y.
Boynton, A. L., Chuquicamata, Chile, S.A.
Brand, F. W., Cleveland, O.
Briggs, E. E., Boston, Mass.
Briggs, H. B., Jr., Philadelphia, Pa.
Brown, L. E., Salt Lake City, Utah
Burns, R. O., Jr., New York, N. Y.
Calderwood, E. M., Spokane, Wash.
Campion, G. H., Chicago, Ill.
Caparo, J. A., (Member), Notre Dame, Ind.

Carlson, E. O., New York, N. Y.
Carpenter, A. B., Camden, N. J.
Catherwood, W. S., Jr., (Member), Brooklyn, N. Y.
Chaffee, J. W., Milwaukee, Wis.
Chandler, W. D., (Member), New York, N. Y.
Chesney, R. M., (Member), Youngstown, O.
Cheverton, J. A., Milwaukee, Wis.
Clapham, H. E., Chicago, Ill.
Clarke, F., New York, N. Y.
Cole, H. M., Springfield, Mass.
Dikeman, H. C., New York, N. Y.
Di Pietro, V., New York, N. Y.
Donnelly, A. L., Philadelphia, Pa.
Dowman, W., New York, N. Y.
Drake, C., New York, N. Y.
Draper, G. W. E., New York, N. Y.
Duncan, J. McA., Pittsburgh, Pa.
Dunkelberger, L. E., Brooklyn, N. Y.
Edelstein, J. E., Minneapolis, Minn.
Edwards, W. W., Boston, Mass.
Eichert, W., (Member), Brooklyn, N. Y.
Eidam, E. G., Rochester, N. Y.
Eldridge, H. W., New York, N. Y.
Elsasser, H. W., New York, N. Y.
Espenschied, L., New York, N. Y.
Farlinger, W. H., New York, N. Y.
Felder, S. I., New York, N. Y.
Ferguson, J. G., New York, N. Y.
Ferreri, P., New York, N. Y.
Fich, M., New York, N. Y.
Fitch, H. S., Pittsburgh, Pa.
Fransson, F. J., Cambridge, Mass.
Frase, J. MacC., Ft. Wayne, Ind.
Frazier, G. A., E. Pittsburgh, Pa.
Freed, L., Toledo, O.
French, H. G., Schenectady, N. Y.
Frisch, W. F., Ft. Wayne, Ind.
Gettinger, R. F., E. Pittsburgh, Pa.
Gibbon, C. O., Cambridge, Mass.
Goodwin, E. P., New York, N. Y.
Green, R. J., Boston, Mass.
Greene, S. E., Pittsfield, Mass.
Guruce, DeB., New York, N. Y.
Gust, R. H., Denver, Colo.
Hall, G. R., Toronto, Ont.
Hammond, C.R., (Member), Milwaukee, Wis.
Harrer, W. J., E. Pittsburgh, Pa.
Hastings, L. B., Dayton, O.
Hawley, H. G., Toronto, Ont.
Heald, G. D., New York, N. Y.
Hellman, C. F., Ft. Wayne, Ind.
Hershey, Q. W., E. Pittsburgh, Pa.
Hertz, A., New York, N. Y.
Hicklin, J. W., Schenectady, N. Y.
Higbee, B. P., New York, N. Y.
Hilborn, H. H., Brooklyn, N. Y.
Hillock, E. H., Long Island City, N. Y.
Hoch, A. J., New York, N. Y.
Hoffer, LeR. H., Brooklyn, N. Y.
Hogan, D. J., New York, N. Y.
Holmes, H. S., Brooklyn, N. Y.
Hornbeck, H. W., New York, N. Y.
Huebner, C. A., Pittsburgh, Pa.
Huey, G. W., E. Pittsburgh, Pa.
Humphrey, A. G., New York, N. Y.
Hyer, R. G., Mt. Vernon, N. Y.
Ilgner, H. F., Milwaukee, Wis.
Istell, D. D., Philadelphia, Pa.
James, A. E., Spokane, Wash.
Jenkins, R. T., New York, N. Y.
Jensen, L., New York, N. Y.
Jensen, O. E. R., New York, N. Y.
Johnson, A., Brooklyn, N. Y.
Johnston, A. C., Toronto, Ont.
Jones, H. E., Denver, Colo.
Jones, R. A. Schenectady, N. Y.
Jones, R. H., Madison, Wis.
Jones, W. O., Schenectady, N. Y.
Joubert, L. P., Seattle, Wash.
Kahn, L., New York, N. Y.
Kane, E. V., Milwaukee, Wis.
Kendell, B. W., (Member), New York, N. Y.
Kerr, M. B., New York, N. Y.
Kime, R. R.,(Member),New York, N.Y.
Koenig, H. C., New York, N. Y.
Landt, N. A., Portage, Wis.
Lanphier, B., New York, N. Y.
Larsen, L. E., Anaconda, Mont.
Le Clair, C., Peekskill, N. Y.
Lemmon, V. W., New York, N. Y.
Lewis, J. W., E. Pittsburgh, Pa.
Lewis, W., S. Bethlehem, Pa.
Livingston, P. C., Syracuse, N. Y.
Longtin, O. E., North Fork, Cal.
Lorentz, H. E., New York, N. Y.
Luther, A. L., Big Creek, Cal.
Macfarland, H. D., Mt. Vernon, N. Y.
Magee, R. R., New York, N. Y.
Marr, A. P., New York, N. Y.
May, C. W. H., Pottsville, Pa.
Mayer, J. N., New York, N. Y.

Meagher, G. J., Seattle, Wash.
Menkel, H. S., New York, N. Y.
Milburn, W. R., Milwaukee, Wis.
Millar, W. K., Big Creek, Cal.
Miller, J. E., Milwaukee, Wis.
Mitchell, E. H., (Member), Ft. Worth, Tex.
Montgomery, L. J., Long Island City, N. Y.
Moody, R. E., Milwaukee, Wis.
Morgan, W. A., Jr., New York, N. Y.
Morris, R. W., New York, N. Y.
Muth, A. J., Chisholm, Wis.
McCain, M., Spokane, Wash.
McCandless, E., E. Pittsburgh, Pa.
McCusker, B. S., New York, N. Y.
McLaurin, D. S., Little Rock, Ark.
McLean, G. L., Pittsburgh, Pa.
Neal, R. A., E. Pittsburgh, Pa.
Noble, C. S., Seattle, Wash.
Noller, C. W., New York, N. Y.
Nordenswan, R., New York, N. Y.
Ogden, C. E., Cincinnati, O.
O'Neill, C. F., New York, N. Y.
O'Neill, H. W., New York, N. Y.
Paige, N. F., New York, N. Y.
Paquette, P. C., New York, N. Y.
Park, C. D., New York, N. Y.
Parrott, R. P., Harrison, N. J.
Pawlick, O. A., New York, N. Y.
Penn, J. E., Cleveland, O.
Petersen, H., Milwaukee, Wis.
Prescott, G. A., Quincy, Mass.
Pumphrey, R. E., Ft. Wayne, Ind.
Ralston, T. N., E. Pittsburgh, Pa.
Reid, E. J., Montreal, Que.
Reid, P. H., Niagara Falls, N. Y.
Renshaw, E. N., New York, N. Y.
Rhine, C. P., Fresno, Cal.
Richardson, A. H., Worcester, Mass.
Ringstad, E., E. Pittsburgh, Pa.
Rogers, J. B., Ensenada, Porto Rico
Rosencrance, H. L., New York, N. Y.
Rowan, F. H., Niagara Falls, N. Y.
Rumsey, W. W., Milwaukee, Wis.
Runey, L. C., Boston, Mass.
Sanborn, J. F., New York, N. Y.
Sargeant, E. C., New York, N. Y.
Seacord, D. F., New York, N. Y.
Seem, R. W., Stanislaus, Cal.
Shaver, A. V., Ft. Wayne, Ind.
Simpson, R. L., New York, N. Y.
Sinclair, C. G., Jr., New York, N. Y.
Slough, F. M., Rochester, N. Y.
Smith, N. E., Woonsocket, R. I.
Smith, R., Longmont, Colo.
Smith, W. J., New York, N. Y.
Sparkes, H. P., E. Pittsburgh, Pa.
Spears, R. L., E. Pittsburgh, Pa.
Stackhouse, R. C., E. Pittsburgh, Pa.
Standish, M. E., Milwaukee, Wis.
St. Clair, A., Philadelphia, Pa.
Stephens, C. E., New York, N. Y.
Stevenson, R. R., Toronto, Ont.
Stiener, C. R., New York, N. Y.
Stoeltzing, L. F., Brooklyn, N. Y.
Stone, O. B., Atlanta, Ga.
Stopplemann, F. H., E. Pittsburgh, Pa.
Tabb, W. T., Milwaukee, Wis.
Talbot, E. D., New York, N. Y.
Templeton, W. B., Spokane, Wash.
Teevan, G. B., (Member), Brooklyn, N. Y.
Treene, W. H., Schenectady, N. Y.
Tuck, A. E., Jr., Philadelphia, Pa.
Varner, M. K., St. Louis, Mo.
Velander, F. E. H., Cambridge, Mass.
Voce, W. A., Toronto, Ont.
Vogelsang, G., (Member), Waterbury, Conn.
Volpe, J. S., Ashland, Ore.
Walton, E. R., Milwaukee, Wis.
Ward, G. M., Seattle, Wash.
Ward, O. M., Milwaukee, Wis.
Weber, C., Milwaukee, Wis.
Wells, J. D., 2nd, Denver, Colo.
Wheeler, J. J., New York, N. Y.
White, T. K., New York, N. Y.
Williamson, V. B., New York, N. Y.
Witmer, J. S., Jr., New York, N. Y.
Wolff, E. E., New York, N. Y.
Woods, G. M., E. Pittsburgh, Pa.
Wroath, L. H., New York, N. Y.
Zieg, C. V., Ft. Wayne, Ind.
Total 216.

STUDENTS ENROLLED FEBRUARY 14, 1918

9435 Hunt, J. J., Armour Inst. of Tech.
9436 Erickson, R.A., Armour Inst. of Tech.
9437 Sloan, C. G., Jr., Univ. of Missouri
9438 Naylor, J. M., Purdue Univ.
9439 Stockton, W. V., Jr., Purdue Univ.
9440 Bieck, W. H., School of Engg. of Milwaukee
9441 Bocher, H. W., School of Engg. of Milwaukee

9442 Ilyus, E. B., Lehigh Univ.
9443 Mayor, R., Jr., Villanova Coll.
9444 Gersman, B., School of Engg. of Milwaukee
9445 Hawe, J. E., Ohio Northern Univ.
9446 Herber, J. C., Cooper Union
9447 Yamada, H., Ohio State Univ.
9448 Vaughan, J. W., Jr., Georgia School of Tech.
9449 Brown, J. D., Union Univ.
9450 Clarke, H. A., Union Univ.
9451 Parks, E. S., Clarkson School of Tech.
9452 Hasemeier, S., Engg. School of Milwaukee
9453 Smith, A. K., Jr., Throop Coll. of Tech.
9454 Blakeslee, H. G., Ohio State Univ.
9455 Granger, G., Georgia School of Tech.
9456 Kinney, H. C., Pratt Institute
9457 Boyer, I. B., Georgia School of Tech.
9458 Kelly, E., Georgia School of Tech.
9459 Hudson, R. C., Clarkson School of Tech.
9460 Turner, H. L., Jr., Georgia School of Tech.
9461 Hoyt, R. H., Clarkson Coll. of Tech.
9462 Berry, O. F., Ohio No. Univ.
9463 Bull, W. E., Univ. of Ill.
9464 Euston, J. H., Univ. of Ill.
9465 Olesen, H. L., Univ. of Ill.
9466 Wien, J. H., Univ. of Ill.
9467 Cross, S. A., Sheffield Scientific Sch.
9468 Silverman, H. H., Ohio. No. Univ.
9469 Zust, H. E., N. Y. Electrical Sch.
9470 Holsing, W. F., Bucknell Univ.
9471 Walker, C. E., Ohio No. Univ.
9472 Kuhn, M. V., School of Engg. of Milwaukee
9473 Tompkins, E. R., School of Engg. of Milwaukee
9474 Wienecke, V. C., School of Engg. of Milwaukee
9475 Duff, C. K., Univ. of Toronto
9476 McLeod, E. W., Univ. of Toronto
9477 Earl, J. F., Univ. of Toronto
9478 Cheney, I. L., Clarkson Coll. of Tech.
9479 Fisher, H. C., Finley Engg. Coll.
9480 Garman, R. W., Purdue Univ.
9481 Pergande, A. G., Univ. of Wis.
9482 Flatman, G. J., Univ. of Wis.

Total 48.

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street.

Louis D. Rees
(former address)
Gray Apartments,
Wilkinsburg, Pa.

Ernest A. Thiele
(former address)
25 Faber St.,
Port Richmond, N. Y.

H. C. Von Rosenberg
(former address)
713 South Ave.
Wilkinsburg, Pa.

PERSONAL

C. E. Bennett has accepted the position of Assistant to Chas. G. Adsit, Consulting Engineer, Georgia Railway and Power Co., Atlanta, Ga.

H. W. Deininger for several years Vice President and Gen'l Manager of the Sac City Electric Co., and for the past two years manager of the Sac City district for the Iowa Light, Heat and Power Co., has resigned and accepted the position of General Superintendent of the Iowa Southern Utilities Co., with headquarters at Centerville, Ia.

George L. Hedges has resigned his position with the Kelman Electric & Mfg. Co. of Los Angeles to report to Washington, D. C., for active duty as First Lieutenant, Ordnance Department, R. C.

William A. Del Mar was married on Thursday, January 31, 1918 to Miss Breta Longacre. Mr. Del Mar is a member of the Board of Directors of the Institute, the Standards Committee and the Traction and Transportation Committee.

STEPHEN A. STAEGE announces the dissolution of the firm of Staege & Dewey and his continuation as Consulting Engineer with officers in the Light and Power Bldg., Watertown, N. Y.

GEORGE J. NEWTON, Underground Distribution Specialist, is engaged on work for the Crisfield Construction Company. His address will be Room 523 Lillie Building, West Main St., Waterbury, Conn.

EMPLOYMENT BULLETIN

Vacancies. The Institute is glad to learn of desirable vacancies from responsible sources, announcements of which will be published without charge in the BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Men Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

VACANCIES

V-334. Electrical Draftsman wanted, experienced with central station and transformer sub-station layouts. State full qualifications. Good working conditions and future promise.

V-335. Electrical technical graduate with engineering office and practical testing experience, familiar with power plants including gasoline engines, storage batteries and circuit layouts. Opportunity is with large company giving sick benefits and pensions. Exempt men preferred. Reply should give age, salary wanted, references and date available.

V-336. Wanted: Young men, preferably technical graduates with some experience in telephone switchboard work, to write specifications for telephone switchboards. Telephone company located in the East. State education, experience and salary expected.

V-337. The Western Electric Company has opportunities for physicists, engineers, designers and draftsmen for work of research, development and design, related to problems of telephonic, telegraphic and radio communication which are matters of public importance. Both temporary and permanent positions are open. Apply by letter, not in person unless so specifically requested, to F. B. Jewett, Chief Engineer, 463 West St., New York, N. Y.

V-338. Technical men with experience in testing electrical equipment wanted by a large operating company in Pennsylvania. The duties will consist of checking new equipment being installed and locating trouble in apparatus already in service. Give full details regarding experience, education and salary desired.

V-339. Wanted: Young technical man to assist in sales correspondence and in experimental work, primarily as assistant to executive. Prefer a man recently graduated from technical school and one who is exempt from military service. Excellent opportunity for growth.

MEN AVAILABLE

907. Electromagnet Engineer, age 27, married, eight years' experience in design, manufacture and compiling specifications for electromagnets, solenoids, secondary and field windings, check magnets, including their application and laboratory experiments, also modern winding methods and construction. Can handle problem from design to finished product. Salary $225 per month.

908. Designing Electrical Engineer, technical graduate, with broad experience in electrical and mechanical design of D-C. and A-C. high and low speed motors and generators, and with a good record of practical results. Has also had some experience in design of steam engines and turbines. Age 35 and married. Minimum salary $2500.

909. Mechanical and Electrical Engineer, technical graduate, original and practical. Have had best of experience both in shops and office. Have designed and put into successful operation machine tools, electrically operated valves, magnetic clutches, gunboring equipment and systematizing. Can handle men and get results. Prefer

engineering or manufacturing. Salary $5000.

910. Graduate electrical engineer, Mem. A. I. E. E., Assoc. I. E. E., London; married, with wide experience in construction, maintenance and management of electric light and tramway power plants. Has been engaged abroad for over eighteen years. Position in California or other southern states preferred.

911. Electrical engineering graduate, with one year's experience in operating and construction work, one year's experience in the design of large substations and generating stations, now completing the layout of electrical equipment of steel rolling mill, a contributor to technical magazines; desires position with progressive company in Chicago or farther West.

912. Electrical Engineer, technical graduate. Six years design, manufacture, and test of electrical machinery. Eight years design, construction, and test of electrical stations, underground transmission, and industrial lighting. Three years business. Now employed. Want position as engineer or assistant with light and power company.

913. Chief Electrician or electrical engineer for industrial plant or mine. Technical graduate, twelve years' experience on G. E. testing, draftsman and chief electrician. Past six years chief electrician large industrial plant and shipyard. Least salary $200 for permanent position. Available on thirty days notice.

914. Professor of Electrical Engineering and Physics of wide experience in practise and teaching will be open for engagement in short time. Member A. I. E. E.

915. General Manager and Chief Engineer of large public utility company desires change and will consider position requiring executive ability and experience in line of public utility work or other interests. Correspondence invited and detailed information will be furnished on request or personal interviews if desired.

916. Graduate Electrical Engineer, age 25, one year's experience, desires to make change. Location in New York or vicinity preferred.

917. Electrical Engineer, Chief Electrician, Assoc. A. I. E. E., technical education, ten years' experience layout, installation and maintenance, desires position with industrial concern. Prefer company doing government work.

918. University graduate, post graduate degree electrical engineer, age 37, two years university instructor, ten years engineering office experience. Specialized in compilation of engineering data, preparation and editing technical articles, familiar with printing and engraving work. Able to go out after data and bring it back. Salary $3500.

919. Electrical Engineer '12; age 28, varied experience, wiring drafting, inspecting, electrical testing, and last two years transformer designing. Exempt from military service. Will give new ideas to a company in the Middle West as regards transformers. Salary $110. Must be free to act.

920. Electrical Engineer, technical graduate, with broad practical engineering experience, well versed in power plant and transmission line work and the utilization of electric power. Capable and accustomed to handling engineering problems. In present position for the last six years. Ohio or adjoining states preferred. Age 35, salary $1800.

921. Electrical Engineer, eight years' experience in charge steam and hydroelectric plants, two years commercial power engineer, desires change on one month's notice to present employers. Consider position as power engineer, superintendent of hydroelectric plant, or will travel. Speak Spanish, technical education. Age 32, married. Minimum salary $3000.

922. Electrician, technical school graduate, eight years of wide electrical experience with motors, generators both A-C. and D-C., transformers and storage batteries; age 25. Available on two weeks notice. Salary $140.

923. Graduate Electrical Engineer, ten years' varied experience electric power generation, transmission, distribution and utilization, including railroad electrification. Also installation electrical equipment, including power station and substation work. Desires responsible position on large power system or on construction work. Available March fifteenth. Present salary $2400.

924. Practical electrical engineer, age 29, married, desires to relocate, preferably in extreme southwest. Experienced in supervision, design and operation of high and low voltage power and substations. Classified IV-A in draft. Dissatisfied with climate of present location. With present (central station) company fifteen years. Offer must be permanent. Salary $3000.

ACCESSIONS TO THE UNITED ENGINEERING SOCIETY LIBRARY

(From January 1, 1918 to February 1, 1918.)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made. These are taken either from the preface or the text of the book.

All the books listed may be consulted in the United Engineering Society Library.

AN INTRODUCTION TO THE STUDY OF LANDSCAPE DESIGN.

By Henry Vincent Hubbard and Theodora Kimball. N. Y., The MacMillan Co., 1917. 20+406 pp., 40 illus., 36 pl., 11x9 in., cloth, $6.

Written, the authors state, to present a general conception of landscape design which may enable a designer better to determine for himself the relations of the objects and ideas with which he is dealing and better to prepare and use in a decisive way, in the individual problems of his profession, the natural aptitudes and acquired knowledge which are the tools of his trade. Contains numerous footnote references and a select bibliography.

APPLIED MOTION STUDY.

A Collection of Papers on the Efficient Method to Industrial Preparedness. By Frank B. Gilbreth and L. M. Gilbreth. N. Y., Sturgis and Walton Co., 1917. 18+220 pp., 7 pl., 1 diagram, 8x5 in., cloth, $1.50.

In these articles which are here reprinted from various periodicals, the authors describe motion study as applied to various fields of activity, and outline its principles and practise so as to make possible its application in any and all lines of work. Contents: What Scientific Management Means to America's Industrial Position; Units, Methods, and Devices of Measurement under Scientific Management; Motion Study as an Industrial Opportunity; Motion Study and Time Study Instruments of Precision; Chronocyclegraph Motion Devices for Measuring Achievement; Motion Models their Use in the Transference of Experience and the Presentation of Comparative Results in Educational Methods; Motion Study for the Crippled Soldier; The Practice of Scientific Management; The Three Position Plan of Promotion; The Effect of Motion Study upon the Workers.

BIOCHEMICAL CATALYSTS IN LIFE AND INDUSTRY.

Proteolytic Enzymes. By Jean Effront. Translated by Samuel C. Prescott assisted by Charles S. Venable. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 11+752 pp., 9x6 in., cloth, $5.

A companion volume to the author's "Enzymes and their Applications," limited to the proteolytic enzymes, or those which act as catalysts for nitrogenous substances. Presents our knowledge of the action of these substances and of their products and describes the application of enzymes to industry. Bibliographies accompany each chapter.

EVERYMAN'S CHEMISTRY.

The Chemist's Point of View and his Recent Work Told for the Layman. By Ellwood Hendrick. N. Y. and Lond., Harper Bros., (copyright 1917). 374 pp., 8x5 in., cloth, $2.

The author has attempted to produce a readable, easily understood account of modern chemistry, with special stress upon its application in actual life, for the use of those without special chemical training. Particular attention is given to industrial chemistry and to the most recent developments of American chemical industry.

FIRST REPORT TO THE COUNCIL OF THE NORTH EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS ON CERTAIN METHODS OF PRODUCING VACUUM.

By Edwin L. Orde, C. Waldie Cairns and J. Morrow. Newcastle-Upon-Tyne North East Coast Institution of Engineers and Shipbuilders, 1916-1917. 34 pp., 16 illus., 1 pl., tab., 12x9 in., paper, 10s. 6d.

Presents the results of a series of experiments on apparatus by which the air is withdrawn from the condenser by means of reciprocating air pumps and that by which air is withdrawn from the condenser by means of fluid jets, by which it is compressed and delivered to the air pumps in a less rarefied state.

FUNDAMENTALS OF NAVAL SERVICE.

By Commander Yates Stirling. Special Chapters by Lieut. Comm. H. C. Mustin, Lieut. Comm. C. S. McDowell and Dr. Ralph Walker McDowell. Phila. and Lond., J. B. Lippincott Co. (copyright 1917). 589 pp., 32 illus., 2 pl., 2 diagrams, 7x5 in., cloth, $2.

Epitomizes a variety of information, usually to be obtained only in many books, in the form

of a manual for those interested in our navy, and who may choose to serve their country on the water.

GENERAL ELECTRIC COMPANY'S MEDICAL SERVICE AND HOSPITAL.

Schenectady, N. Y., General Electric Co., illus., 11x9 in., cloth binder.

A brief account of the methods by which this company cares for the health of its employees, accompanied by a collection of safety bulletins used throughout its plants for educating its workmen in the prevention of accidents.

HYDROELECTRIC POWER STATIONS.

By Eric A. Lof and David B. Rushmore. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 10+822 pp., 407 illus., 2 diagrams, 9x6 in., cloth, $6.

Treats of the hydraulic, electrical and economic factors involved in the planning, construction and operation of these plants, but does not deal with the design of the individual structures, machinery and apparatus of which a power station is composed. The appendixes give a bibliography of American hydroelectric stations and a table of the principal data on transmission systems operating at 70,000 volts or over. Contents: General Introduction; Hydrology; Classification of Developments; Dams and Headworks; Water Conductors and Accessories; Storage Reservoirs; Power House Design; Hydraulic Equipment; Electrical Equipment; Economical Aspects; Organization and Operation Appendix, I. Reference to Descriptions of Plants, II. Principal Data on Transmission Systems Operating at 70,000 volts and above, III. Turbine Testing Code.

INTERIOR WIRING.

And Systems for Electric Light and Power Service, a Manual of Practise for Electrical Workers, Contractors, Architects and Schools. By Arthur L. Cook. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 10+416 pp., 248 illus., 2 diagrams, 7x5 in., flexible cloth, $2.

There are many text-books, the author says, which deal with the principles of operation of electrical apparatus and the methods of calculating electrical circuits, but the usual electrical worker or student does not possess a sufficient background of practical experience to enable him to use these principles to design a wiring installation. In this book an attempt is made to supplement the text-books by giving information which will compensate, in part at least, for a lack of practical experience.

LIGHTHOUSES AND LIGHTSHIPS OF THE UNITES STATES.

By George R. Putnam. N. Y. and Bost., Houghton Mifflin Co.; Cambridge, The Riverside Press, 1917. 13 +308 pp., 36 pl., 9x6 in., cloth, $2.

A record of lighthouse work in this country, and of the main facts as to the lighthouses of the world, together with some account of personal deeds of the light-keepers. The book is planned to give a general and non-technical description of lighthouses, especially in the United States, and a history of their development.

PRACTICAL INSTRUCTIONS.

In the Search for, and the Determination of, the Useful Minerals, Including the Rare Ores. For the Prospector, Miner, and as a Ready Reference for Everybody Interested in the Mineral Industry. By Alexander McLeod. 2d ed. enl. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 27+254 pp., 7x4 in., flexible cloth, $1.75.

This pocket book of prospecting and testing includes simple tests which require no skill and only apparatus and chemicals which are easily obtainable. The second edition contains various additions and corrections, increasing it to three times the length of the first.

PRACTICAL STREET CONSTRUCTION.

Planning Streets and Designing and Constructing the Details of Street Surface, Subsurface and Supersurface Structures. By A. Prescott Folwell. Reprinted from a series of Articles which appeared in "Municipal Journal" during the year 1916. N. Y., Municipal Journal and Engineer, 1916. 248 pp., 151 illus., 9x6 in., cloth, $2.

A discussion of street alignment, grade and cross-section, the location of underground constructions and their surface appurtenances, and the other features of city streets, especially prepared for the use of city engineers. Appeared originally in Municipal Engineer. Contents: What streets are used for; Planning street alignments; Diagonal thorofares; Planning thorofares; Street planning in Newark; Street widths; Sidewalk widths; Minor residence streets; Local and elastic streets; Philadelphia elastic streets; Street cross-section; Motor tracks and street grades; Street grades; Planning grades; Grade at Intersection; Intersected grades; Gutters; Sidewalks and sidewalk construction; Sidewalk obstructions.

SOIL CONDITIONS AND PLANT GROWTH.

By Edward J. Russell. 3d ed. N. Y. and Lond., Longmans, Green and Co., 1917. 243 pp., 14 illus., 10x6 in., boards, $2.

This volume, which belongs to the series of "Monographs on Biochemistry," edited by R. H. A. Plimmer and F. G. Hopkins, is an attempt to give a concise account of our present knowledge of the soil as a medium for plant life. The third edition has been considerably altered throughout to include recent progress, and a new chapter discussing the collodial properties of the soil has been added. An extensive select bibliography is given.

SPHERICAL BALLOONING.

Some of the Requirements. By P. J. McCullough. Saint Louis, The Mangan Printing Co., (copyright 1917). 46 pp., 11 illus., 9x6 in., paper, $1.

This monograph explains clearly and concisely the proper procedure in assembling and piloting spherical balloons. Intended as a primary text for beginners.

STEAM POWER PLANT ENGINEERING.

By George F. Gebhardt. 5th ed. Rewritten and reset. N. Y., John Wiley and Sons, Inc.; Lond., Chapman and Hall, Ltd., 1917. 16+1057 pp, 642 illus., 1 diagram, 9x6 in., cloth, $4.

This edition follows the plan of the earlier ones, but has been greatly enlarged and entirely re-written so as to include the modern developments of the steam power plant. Supplementary chapters on Elementary Thermodynamics, Properties of steam, and Properties of dry and saturated air have been added.

STREET RAILWAY ACCOUNTING.

A Manual of Operating Practise for Electric Railways. By Irville Augustus May. N. Y., The Ronald Press Co., 1917. 20+454 pp., 212 illus., 9x6 in., ½ mor., $5.

An outline of the working methods developed and actually used by the accounting departments of certain large companies which are operated in accordance with the regulations of the Interstate Commerce Commission as given in its "System of Uniform Accounts for Electric Railways." The author is Vice-President of the American Electric Railway Accountants Association.

TEXT-BOOK OF ORDNANCE AND GUNNERY.

By Lt. Col. William H. Tschappat. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 10+705 pp., 314 illus., 1 diagram, 9x6 in., cloth, $6.50.

A text-book for the senior class at the U. S. Military Academy. Founded on Lissak's "Ordnance and Gunnery," with revisions and new material.

THE EYES OF THE ARMY AND NAVY.

Practical Aviation. By Albert H. Munday. N. Y., & Lond., Harper & Bros. (copyright 1917). 226 pp., 49 illus., 4 pl., 7x5 in., cloth, $1.50.

A handbook intended for the layman with a moderate education who wishes to obtain a practical knowledge of flying and the fundamental principles of air-plane construction, engines, etc. Based on the writer's experience in the Royal Naval Air Service, as an airplane pilot.

THE FLYER'S GUIDE.

An Elementary Handbook for Aviators. By Captain N. J. Gill. N. Y., E. P. Dutton and Co., 1917. 153 pp., 18 illus., 3 pl., 9x6 in., cloth, $2.

Instructions to beginners on methods of flying, the construction and maintenance of air-planes, the theory of flight, internal combustion engine and ignition devices. Intented as a guide to those learning to fly, especially for military pilots.

THE FOUNDATIONS OF NATIONAL PROSPERITY.

Studies in the Conservation of Permanent National Resources. By Richard T. Ely, Ralph H. Hess, Charles K. Leith and Thomas Nixon Carver. N. Y., The MacMillan Co., 1917. 29+378 pp., 8x5 in., cloth, $2.

The title page of this work emphasizes the thought that conservation is to be regarded as a treatment of the foundations of national prosperity. It deals with the permanent causes of the wealth of nations. The titanic war struggle in which we are engaged makes it important to emphasize the fact that in the treatment of conservation we are dealing with national preparedness both for war and peace. There is danger that in dealing with measures of preparedness we may direct our attention too exclusively to the needs of to-day and to-morrow, whereas nothing stands out more clearly as a result of our world war than the fact that preparedness must be a permanent, all-around condition; for otherwise our preparations may be in vain. While it is true that this book deals mainly with permanent conditions of prosperity and preparedness, it also has lessons for the immediate present. Contents: Conservation and Economic Theory; Conservation and Economic Evolution; Conservation of Certain Mineral Resources; Conservation of Human Resources.

THE KILN DRYING OF LUMBER.

A Practical and Theoretical Treatise. By Harry Donald Tiemann. Phila. and Lond., J. B. Lippincott Co., (copyright 1917). 9+316 pp., 54 illus., 1 diagram, 9x6 in., cloth, $4.

The author, who is in charge of the kiln drying experiments of the U. S. Forest Service, describes the structure and properties of wood, the common practises in drying; how wood dries; the principles and methods of kiln drying; the effect of various methods of drying upon the strength of wood, etc. Intended to provide the best available information in systematic form.

THE MICROSCOPE.

An Introduction to Microscopic Methods and to Histology. By Simon Henry Gage. 12 ed., rewritten. Ithaca, The Comstock Publishing Co., 1917. 9+472 pp., 253 illus., 9x6 in., cloth, $3.

This edition, the author states, has been more thoroughly revised than any of its predecessors, and includes those new developments in processes and apparatus that he has found helpful by personal tests. Micro-chemistry and metallography have been omitted from this edition as adequate special text-books on these subjects are now available.

THEORY AND OPERATION OF DIRECT-CURRENT MACHINERY.

Prepared in the Extension Division of the University of Wisconsin. By Cyril M. Jansky. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1917. 10+285 pp., 214 illus., 9x6 in., cloth, $2.50.

A text-book prepared by the Extension Division of the University of Wisconsin for students of limited mathematical training. An elementary course in the principles involved, their applications in construction, and the operation and care of the machines.

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Revised to March 1, 1918.

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E. W. Rice, Jr.

Term expires July 31, 1922.
C. A. Adams, L. A. Ferguson,
S. W. Stratton.

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1918.
L. T. Robinson, Harold Pender,
C. E. Skinner.

Term expires July 31, 1919.
B. A. Behrend, Frederick Bedell,
A. S. McAllister.

Ex-Officio.

E. W. Rice, Jr., President,
George A. Hamilton, Treasurer,
F. L. Hutchinson, Secretary

STANDARDS COMMITTEE.

C. A. Adams, Chairman,
Massachusetts Institute of Technology, Cambridge, Mass.
Harold Pender, Secretary,
University of Pennsylvania, Philadelphia, Pa.
P. G. Agnew, F. C. Hanker,
Frederick Bedell, H. M. Hobart,
Joseph Bijur, Henry D. James,
L. F. Blume, P. Junkersfeld,
James Burke, A. E. Kennelly,
G. A. Burnham, G. L. Knight,
N. A. Carle, F. A. Laws,
P. H. Chase, A. S. McAllister,
E. J. Cheney, W. L. Merrill,
H. H. Clark, Harold S. Osborne,
E. H. Colpitts, Charles Robbins,
F. P. Cox, L. T. Robinson,
William A. Del Mar, C. H. Sharp,
A. M. Dudley, C. E. Skinner,
E. J. Edwards, N. W. Storer,
H. W. Fisher, John B. Taylor,
W. S. Gorsuch, R. B. Williamson.

SUBCOMMITTEES OF THE STANDARDS COMMITTEE.

No. 1. Temperature Measurements (Field Coils)
Kennelly, A. E., Chairman
Agnew, P. G.
Harnden, J. D.
Laws, F. A.
Sharp, C. H.
Skinner, C. E.
Taylor, John B.
Williamson, R. B.

No. 2. Power Costs.
Gorsuch, W. S., Chairman
Carle, N. A.
Cheney, E. J.
Knight, G. L.

No. 3. Standards Relating to Meters
Cox, F. P., Chairman
Bradshaw, W.
Laws, F. A.
Roller, F. W.
Sharp, C. H.

No. 4. Wires and Cables
Del Mar, W. A., Chairman
Chase, P. H.
Clark, Leroy
Clark, Wallace
Day, Maxwell, W.
Elden, L. L.
Fisher, H. W.
Laws, F. A.
Martin, C. B.
Meyer, E. B.
Rosa, E. B.
Skinner, C. E.
Sykes, W.
Torchio, P.

No. 5. Radio, Telephony and Telegraphy
Kennelly, A. E., Chairman
*Blackwell, A. O.
Hogan, John L., Jr.

No. 8. Transformers (Cooperating with N. E. L. A. and Power Club)
Knight, G. L., Chairman
Blume, L. F.
Carle, N. A.
McConahey, W. M.
Taylor, John B.

No. 9. British Rules
Skinner, C. E., Chairman
Hobart, H. M.

No. 10. Dielectric Tests of Machinery
Knight, G. L., Chairman
Chase, P. H.
Junkersfeld, P.
Robbins, Charles
Robinson, L. T.
Torchio, P.

No. 11. Distortion of Wave Form
Osborne, H. S., Chairman
Adams, C. A.
Bedell, F.
Chubb, L. W.
Copley, A. W.
Farmer, F. M.
Robinson, L. T.

No. 12. Electric Traction (Excluding Automobiles)
Del Mar, W. A., Chairman
Eveleth, C. E.
McAllister, A. S.
Storer, N. W.

No. 13. Lightning Protection
Robinson, L. T., Chairman
Chubb, L. W.
Thomas, P. H.

No. 14. Standard Voltages (Cooperating with N. E. L. A. and Power Club)
Carle, N. A., Chairman
Agnew, P. G.
Robbins, Charles
Merrill, W. L.

No. 15. Storage Batteries
Harris, S. C., Chairman
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Goettling, G. M. W.
Hering, Carl
Pender, Harold
Woodbridge, J. L.

No. 16. Explanatory Notes on Rules
Hobart, H. M. (Committee of one)

*Non-members of the Institute.

No. 18. Joint Committee on Metric System
Kennelly, A. E., Chairman
Agnew, P. G.
Sharp, C. H.

No. 20. Circuit Breakers and Switches
Burnham, G. A., Chairman
Carle, N. A.
Hewlett, E. M.
James, H. D.
Mahoney, J. N.

No. 20A. Industrial Controllers
James, H. D., Chairman
Barnum, T. E.
Burnham, G. A.
Friedlaender, E.
Knight, C. D.

No. 21. Form but Not the Substance
Del Mar, W. A., Chairman
Hobart, H. M.
Le Maistre, C.
Merrill, W. L.
Pender, Harold
Robbins, Charles

No. 23. Automobiles
Bijur, Joseph, Chairman
Schoepf, T. H.

No. 25. Conference Committee on Cooperation in Technical Subjects
Robbins, Charles, Chairman
Knight, G. L.

No. 26. Symbols
Agnew, P. G., Chairman
Cheney, E. J.
Colpitts, E. H.
Merrill, W. L.

No. 31. Code Revision
Cheney, E. J., Chairman
Hobart, H. M.
Moore, R. W. E.
Sargent, H. R.

No. 32. Needles for Spark Gap
Robinson, L. T.

No. 33. French Translation
Mailloux, C. O., Chairman
Blondel, A. E.
Garfield, A. S.
Latour, M. C. A.
*Picou,

No. 34. Boiler Code
Carle, N. A., Chairman
Knight, G. L.

No. 35. Class B Insulation and Internal Temperatures of Large Turbo-Alternators
Skinner, C. E., Chairman
Carle, N. A.
Hobart, H. M.
Knight, G. L.
*Mueller, E. F.
Taylor, John B.
Torchio, P.
Williamson, R. B.

No. 36. Efficiency of Compound Interpole Synchronous Converters
Burke, James, Chairman
Hobart, H. M.
Robbins, Charles

No. 38. Terminal Markings (Cooperating with N. E. L. A. and Power Club)
Knight, G. L., Chairman
Blume, L. F.
Taylor, John B.

No. 39. Representation on N. E. L. A. Committee on Valuation Terminology
Carle, N. A., Chairman
Cheney, E. J.
Gorsuch, W. S.

TECHNICAL COMMITTEES.

Revised to March 1, 1918.

POWER STATIONS.

Philip Torchio, Chairman,
N. Y. Edison Company, 124 E. 15th St., New York.

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Niagara Falls Power Company, Niagara Falls, N. Y.

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TRACTION AND TRANSPORTATION.

N. W. Storer, Chairman,
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G. N. Chamberlin, C. E. Clewell, J. R. Cravath, Bassett Jones, T. S. Perkins, R. C. Powell, E. B. Rosa, W. D'A. Ryan, Clayton H. Sharp, W. M. Skiff.

ECONOMICS OF ELECTRIC SERVICE

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Harris Trust Building, Chicago, Ill.

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252 West 29th St., New York

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104 East 32nd St., New York.

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Pittsburgh Crucible Steel Co., Midland, Pa.

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EDUCATIONAL.

E. J. Berg, Chairman,
Union College, Schenectady, N. Y.

Alexander M. Gray, Charles S. Howe, E. A. Loew, E. B. Merriam, Chester W. Rice, C. E. Skinner, W. I. Slichter.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

Paul M. Lincoln, H. W. Buck.
John J. Carty. E. W. Rice, Jr

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Samuel Sheldon, Calvert Townley.
L. T. Robinson.

ON LIBRARY BOARD OF UNITED ENGINEERING SOCIETY.

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Edward D. Adams, W. I. Slichter,
F. L. Hutchinson.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The chairman of the Institute's Code Committee.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

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ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

W. S. Franklin, G. W. Pierce.

ON ADVISORY BOARD OF AMERICAN YEAR-BOOK.

Edward Caldwell.

ON U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION.

A. E. Kennelly, C. O. Mailloux,
Clayton H. Sharp.

ON JOINT COMMITTEE ON CLASSIFICATION OF TECHNICAL LITERATURE.

F. B. Jewett.

ON PAN-AMERICAN ENGINEERING COMMITTEE.

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John H. Finney Charles W. Stone,
Calvert Townley.

ON NATIONAL JOINT COMMITTEE ON OVERHEAD AND UNDERGROUND LINE CONSTRUCTION.

Farley Osgood, Percy H. Thomas.

AMERICAN COMMITTEE ON ELECTROLYSIS.

Bion J. Arnold, F. N. Waterman,
Paul Winsor.

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E. W. Rice, Jr., C. E. Skinner.
N. A. Carle,

ENGINEERING COMMITTEE OF THE NATIONAL RESEARCH COUNCIL.

F. B. Jewett, Clayton H. Sharp.

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C. A. Adams, N. A. Carle,
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COMMITTEE ON GENERAL ENGINEERING, ADVISORY COMMISSION OF THE COUNCIL OF NATIONAL DEFENSE.

H. W. Buck, C. A. Adams.

COMMISSION OF WASHINGTON AWARD

John Price Jackson, Charles F. Scott.

LOCAL HONORARY SECRETARIES.

Guido Semenza, N. 10 Via S. Radegonda, Milan, Italy.

Robert Julian Scott, Christchurch, New Zealand.

T. P. Strickland, N. S. W. Government Railways Sydney, N. S. W.

W. G. T. Goodman, Adelaide, South Australia.

James S. Fitzmaurice, Perth, West Australia.

L. A. Herdt, McGill Univ., Montreal, Que.

Henry Graftio, Ministry of Ways of Communication, Petrograd, Russia.

A. S. Garfield, 45 Boulevard Beausejour Paris 16 E. France.

Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.

John W. Kirkland, Johannesburg, South Africa.

LIST OF SECTIONS

Revised to March 1, 1918.

Name and when Organized		Chairman	Secretary
Atlanta	Jan. 19, '04	A. M. Schoen	Thomas C. Taliaferro, S. E. Underwriters Ass'n., Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead	L. M. Potts, Industrial Bldg., Baltimore, Md.
Boston	Feb. 13, '03	H. M. Hope	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago	1893	Wm. J. Crumpton	C. A. Keller, Edison Building, Chicago, Ill.
Cleveland	Sept. 27, '07	C. N. Rakestraw	C. S. Ripley, 711 Williamson Building, Cleveland, Ohio.
Denver	May 18, '15	Norman Read	Robert B. Bonney, 806 Telephone Building, Denver, Colo.
Detroit-Ann Arbor	Jan. 13, '11	H. H. Higbie	H. J. Wyckoff, Detroit Edison Company, Detroit, Mich.
Erie	Jan. 11, '18	Clayton P. Yoder	Scott S. Hill, General Electric Co., Erie, Pa.
Fort Wayne	Aug. 14, '08	J. J. Kline	R. B. Roberts, G. E. Co., Fort Wayne, Ind.
Indianapolis-Lafayette	Jan. 12, '12	H. O. Garman	E. L. Carter, Public Service Commission of Indiana, State House, Indianapolis, Ind.
Ithaca	Oct. 15, '02	F. Bedell	Alexander Gray, Cornell Univ., Ithaca, N. Y.
Kansas City, Mo.	Apr. 14, '16	W. F. Barnes	W. F. Barnes, 1012 Baltimore Ave., Kansas City, Mo.
Los Angeles	May 19, '08	Don Morgan	A. W. Nye, University of Southern California, Los Angeles, Cal.
Lynn	Aug. 22, '11	J. M. Davis	R. D. Thomson, General Electric Company, West Lynn, Mass.
Madison	Jan. 8, '09	J. R. Price	L. E. A. Kelso, University of Wisconsin, Madison, Wis.
Mexico	Dec. 13, '07		
Milwaukee	Feb. 11, '10	Arthur Simon	Soren H. Mortensen, Allis-Chalmers Mfg. Co., West Allis, Wis.
Minnesota	Apr. 7, '02	F. W. Springer	A. B. King, Electric Machinery Company, Minneapolis, Minn.
Panama	Oct. 10, '13	C. J. Embree	William F. Connell, Balboa Heights, C. Z.
Philadelphia	Feb. 18, '03	Nathan Hayward	H. Mouradian, Bell Telephone Co. of Penna., Philadelphia, Pa.
Pittsburgh	Oct. 13, '02	F. E. Wynne	G. M. Baker, G. E. Co., Oliver Building, Pittsburgh, Pa.
Pittsfield	Mar. 25, '04	F. F. Brand	Neil Currie, Jr., General Electric Company, Pittsfield, Mass.
Portland, Ore.	May 18, '09	E. D. Searing	R. M. Boykin, North Coast Power Co., Portland, Oregon.
Rochester	Oct. 9, '14	Frank C. Taylor	C. T. Wallis, 138 Fairview Avenue, Rochester, N. Y.
St. Louis	Jan. 14, '03	H. W. Eales	Benjamin F. Thomas, Jr., 3869 Park Ave., St. Louis, Mo.
San Francisco	Dec. 23, '04	L. R. Jorgensen	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady	Jan. 26, '03	W. L. Upson	L. F. Millham, General Electric Company, Schenectady, N. Y.
Seattle	Jan. 19, '04	J. Harisberger	G. Dunbar, Seattle Light and Power System, Seattle, Wash.
Spokane	Feb. 14, '13	Charles A. Lund	J. E. E. Royer, Washington Water Power Company, Spokane, Wash.
Toledo	June 3, '07	W. A. Hill	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio.
Toronto	Sept. 30, '03	William G. Gordon	Ernest V. Pannell, 60 Front Street, West, Toronto, Ont.
Utah Section	Mar. 9, '17	A. S. Peters	H. T. Plumb, Newhouse Bldg., Salt Lake City, Utah.
Urbana	Nov. 25, '02	L. V. James	A. R. Knight, Univ of Illinois, Urbana, Ill.
Vancouver	Aug. 22, '11	R. F. Hayward	T. H. Crosby, Canadian Westinghouse Co. Vancouver, B. C
Washington, D. C.	Apr. 9, '03	Paul G. Agnew	J. Ernest Smith, McKinley Manual Training School, Washington, D. C.

Total 34

LIST OF BRANCHES

Name and when Organized		Chairman	Secretary
Agricultural and Mech. College of Texas	Nov. 12, '09	L. E. Tighe	F. V. Murrah, College Station, Tex.
Alabama Poly. Inst.	Nov. 10, '16	W. W. Hill	J. A. Douglas, P.O. Box 190, Auburn, Ala.
Alabama, Univ. of	Dec. 11, '14		
Arkansas, Univ. of	Mar. 25, '04	E. P. O'Neal	J. C. Douthit, University of Arkansas, Fayetteville, Ark.
Armour Institute	Feb. 26, '04	R. A. Newlander	A. A. Hofgren, 7542 So. Chicago Ave., Chicago, Ill.
Brooklyn Poly. Inst.	Jan. 14, '16	G. Hotchkiss	E. A. Demonet, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University	May 17, '10	C. W. Mason	Leon H. Noll, Bucknell University, Lewisburg, Pa.
California, Univ. of	Feb. 9, '12	A. J. Swank	G. F. Teale, University of California, Berkeley, Cal.
Carnegie Inst. of Tech.	May 18, '15	W. F. Eames	B. C. Dennison, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of	Apr. 10, '08		C. B. Hoffman, University of Cincinnati, Cincinnati, Ohio
Clarkson Col. of Tech.	Dec. 10, '15	R. H. Hoyt	E. S. Parks, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col.	Nov. 8, '12		
Colorado State Agricultural College	Feb. 11, '10	R. C. Richards	W. A. Stallings, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized	Chairman	Secretary
Colorado, Univ. of......Dec. 16, '04	Robert Newman	William N. Gittings, University of Colorado, Boulder, Colo.
Georgia School of Technology..............June 25, '14	Reese Mills	Graham Granger, Georgia School of Technology, Atlanta, Ga.
Highland Park College.Oct. 11, '12		
Idaho, Univ of..........June 25, '14	V. E. Pearson	L.J.Corbett,Univ.of Idaho,Moscow,Idaho.
Iowa, Univ. of.........May 18, '09		
Kansas State Agr. Col...Jan. 10, '08	L. N. Miller	M. H. Russell, Kansas State Agri. Col., Manhattan, Kansas.
Kansas Univ. of........Mar. 18, '08	Clarence Lynn	Robert W. Warner, 1428 Tennessee Street, Lawrence, Mass.
Kentucky, State Univ. of Oct. 14, '10	J. M. Hedges, Jr.	Robert M. Davis, State University of Kentucky, Lexington, Ky.
Lafayette College.......Apr. 5, '12	Harry C. Hartung	William Lash Lipps, 633 Parsons, Easton, Pa.
Lehigh University......Oct. 15, '02	R. H. Lindsay	R. D. Bean, 40 N. 7th Ave., Bethlehem, Pa.
Lewis Institute.........Nov. 8, '07	Bernard Slater	Edwin, Verrall, Lewis Institute, Chicago.
Maine Univ. of.........Dec. 26, '06		
Massachusetts Inst. of Tech................Apr. 13, '17	Wm. H. Costello	George A. Elz, Massachusetts Institute of Tech., Cambridge, Mass.
Michigan, Univ. of......Mar. 25, '04	W. R. Harvey	T. W. Conant, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of.....May 16, '16	Russell Ross	Ray McKibben, University of Minnesota, Minneapolis, Minn.
Missouri Univ. of......Jan. 10, '03	A. C. Lanier	D. P. Savant, University of Missouri, Columbia, Mo.
Montana State Col......May 21, '07	Roy C. Hagen	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of.....Apr. 10, '08	Olin J. Ferguson	Oskar E. Edison, University of Nebraska, Lincoln, Nebraska...
North Carolina Col. of Agr. and Mech. Arts..Feb. 11, '10	F. N. Bell	Landon C. Flournoy, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
North Carolina, Univ. of.Oct. 9, '14		
North Dakota, Univ. of..Feb. 15, '17	D. F. McConnell	Roy A. Wehe, University ,N. D.
Norwich University.....June 28, '16		
Ohio Northern Univ....Feb. 9, '12	W. F. Parsons	A. J. Ferlic, 718 N. Main Street Ada, Ohio.
Ohio State University...Dec. 20, '02	E. S. Gunn	T. D. Robb, 124 West 10th Ave., Columbus, Ohio.
Oklahoma Agricultural and Mech. Col...........Oct. 13, '11		
Oklahoma, Univ. of.....Oct. 11, '12	C. T. Hughes	C. H. Whitwell, University of Oklahoma, Norman, Okla.
Oregon Agr. Col........Mar. 24, '08	L. Happold	Lawrence Fudge, Oregon Agri. College, Corvallis, Ore.
Penn. State College....Dec. 20, '02	H. A. Billig	P. J. F. Derr, State College, Pa.
Pittsburgh, Univ. of....Feb. 26, '14		
Purdue University......Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Queen's University (Ont.) Jan. 11, '18		
Rensselaer Poly. Inst....Nov. 12, '09	W. J. Williams	Leroy C. Witt, Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst....Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terra Haute, Ind.
Stanford Univ..........Dec. 13, '07	C. H. Suydam	Frank Miller, Stanford University, Cal.
Syracuse Univ..........Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of........Feb. 14, '08		
Throop College of Technology..............Oct. 14, '10		
Virginia Polytechnic Institute..............Jan. 8, '15	Baxter McIntosh	J. A. Carr, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of.......Feb. 9, '12	Charles Henderson	J.Arthur Evans, University, Va.
Wash., State Col. of.....Dec. 13, '07	B. Benz	Clarence E. Guse, 393 College Sta., Pullman, Wash.
Washington Univ........Feb. 5, '04	R.W. MacDonald	Walter J. Skrainska, Washington University, St. Louis, Mo.
Washington, Univ. of...Dec. 13, '12	Chas. M. Lubcke	M. A. Whitman, University of Washington, Seattle, Wash.
West Virginia Univ......Nov. 13, '14	H. B. Duling	F. L. Davis, West Virginia University, Morgantown, W. Va.
Worcester Poly. Inst....Mar. 25, '04	B. Luther	N. L. Towle, Worcester Polytechnic Institute, Worcester, Mass.
Yale University........Oct. 13, '11	Brian O'Brien	G. P. Nevitt, 249 Park Street, New Haven, Conn.

Total 58

OPENING ADDRESS BY PRESIDENT E. W. RICE, JR. AT A. I. E E. MIDWINTER CONVENTION FEBRUARY 15, 1918.

MEMBERS of the electrical profession and industry have reason to be pleased with the contributions which they have made for the benefit of the world. While we are glad to think that our science and our industry are fundamentally devoted to the products and conditions of peace, we realize that in the electric light, searchlights, the X-ray, telephones, telegraph, wireless apparatus, electric motors, etc., electricity plays an important part in the grim business of war.

We are in the midst of an extraordinary coal famine, due to causes which it is perhaps undesirable for us to attempt to outline. However, I would like to point out how much worse the situation might have been were it not for the contributions of the electrical engineer; and also how much better our condition might have been if our contributions had been more extensively utilized.

Suppose we assume that the present serious situation is due to a lack of production of coal. It is comforting to consider to what extent conditions surrounding such production have been improved and how the output of our coal mines has been already increased by the use of electrical devices in connection with coal mining—such for example as the electric light, electric coal cutters, electric drills and electric mining and hauling locomotives. I have no figures before me but I think it is a fair assumption that the output of coal mines should have been increased at least 25 per cent on the average by the employment of such electrical devices. If this estimate were cut down to 10 per cent it would still leave a possible increase in the tonnage of coal produced of something like 50,000,000 tons during the past year.

If on the other hand, our situation is not due to a shortage in the production of coal, but rather to the failure of the distributive agencies of the country, which is more probable, it is interesting to see how this difficulty would have been largely removed if the railroads of the country were operated by electricity instead of steam.

Where electricity has been substituted for steam in the operation of railroads, fully 50 per cent increase in available capacity of existing tracks and other facilities has been demonstrated. This increased capacity has been due to a variety of causes, but largely to the increased reliability and capacity, under all conditions of service, of electric locomotives, thus permitting a speeding up of train schedules by some 25 per cent, under average conditions. Of course under the paralyzing conditions which prevail in extremely cold weather, when the steam locomotives practically go out of business, the electric locomotives make an even better showing. It is well known that extreme cold (aside from the physical condition of the traffic rail) does not hinder the operation of the electric locomotive but actually increases its hauling capacity. At a time when the steam locomotive is using up all its energy by radiation from its boiler and engine into the atmosphere, with the result that practically no useful power is available to move the train, the electric locomotive is operating under its most efficient conditions and may even work at a greater load than in warm weather. It may therefore be said that cold weather offers no terrors to an electrified road, but on the contrary, it is a stimulant to better performance instead of a cause of prostration and paralysis.

But this is not all. It is estimated that something like 150,000,000 tons of coal were consumed by the railroads in the year 1917. Now we know from the results obtained from such electrical operation of railroads as we already have in this country that it would be possible to save at least two-thirds of this coal, if electric locomotives were substituted for the present steam locomotives. On this basis there would be a saving of over 100,000,000 tons of coal, in one year.

This is an amount three times as large as the total coal exported from the United States during 1917.

The carrying capacity of our steam roads is also seriously restricted by the movement of coal required for haulage of the trains themselves. It is estimated that fully 16 per cent of the total ton-mileage movement behind the engine drawbar is made up of company coal and coal cars, including in this connection the steam engine tender and its contents. In other words, the useful or revenue carrying capacity of our steam roads could be increased about 10 per cent with existing track facilities by eliminating the entire company coal movement.

I have not mentioned the consumption of oil by the railroads

which we are told amounted in 1915 to something like 40,000,000 barrels, nearly 15 per cent of the total oil produced. This fuel is entirely too valuable to be used in a wasteful manner. It is important for many reasons that such a wonderful fuel as oil should be most economically used, if for no other reason than that it will be needed for the ships of our forthcoming merchant marine, for the tractors that till our fields, and the motor trucks that serve as feeders to our railways.

The possible use of water power should also be considered in this connection. It is estimated that there is not less than 25,000,000 h. p. of water power available in the United States, and if this were developed and could be used in driving our railroads, each horse power so used would save at least six pounds of coal per horse power-hour now burned under the boilers of our steam locomotives. It is true that this water power is not uniformly distributed in the districts where the railroad requirements are greatest but the possibilities indicated by the figures are so impressive as to justify careful examination as to the extent to which water power could be so employed and the amount of coal which could be saved by its use. There is no doubt that a very considerable portion of the coal now wastefully used by the railroads could be released to the great and lasting advantage of the country.

The terrors of these "heatless days" will not have been without benefit if they direct the attention of the people and of our law makers to the frightful waste of two of our country's most valuable assets—our potential water power and our wonderful coal reserves. The first, potential water power, is being largely lost because most of it is allowed to run to waste, undeveloped, unused. The second asset, coal, is wasted for exactly the opposite reason. It is being used but in an extravagant and inefficient manner.

Our water-falls constitute potential wealth which can only be truly conserved by development and use—millions of horsepower are running to waste every day, which once harnessed for the benefit of mankind become a perpetual source of wealth and prosperity.

While the amount of coal in our country is enormous, it is definitely limited. While Providence has blessed us with a princely amount of potential riches in our coal beds, it is known that there is a finite limit to the amount of coal so stored and when this coal is once exhausted, it is gone forever. It is really

terrifying to realize that 25 per cent of the total amount of coal which we are digging from the earth each year is burned to operate our railroads under such inefficient conditions that an average of at least six pounds of coal is required per horse power-hour of work performed.

The same amount of coal burned in a modern central power station would produce an equivalent of three times that amount of power in the motors of an electric locomotive, even including all the losses of generation and transmission from the source of power to the locomotive. Where water power may be utilized, as in our mountainous districts in the West, all of the coal used for steam locomotives can be saved. In the Middle and Eastern states, however, water powers are not sufficient and it will be necessary in a universal scheme of electrification that the locomotives be operated from steam turbine stations, but as I have already stated, the operation of the electrified railroads from steam turbine stations will result in the saving of two-thirds of the coal now employed for equivalent tonnage movement by steam locomotives.

It is therefore not too much to say that if the roads of the country were now electrified that no breakdown of our coal supply, due to failure or distribution, would exist. What this would mean for the comfort of the people and the vigorous prosecution of the war, I will leave for you to imagine.

Of course this picture which I have briefly and inadequately sketched of the great benefits which our country would have received if the roads had been electrified does not improve our present situation and it may be claimed that any discussion of such a subject at this time is of an academic nature. This point of view is, in a sense true, but I think that we can properly take time to consider it because of the effect which it may have upon our future efforts. This picture is not merely an inventors dream but is based upon the solid foundation of actual achievement. We have had enough experience upon which to base a fairly accurate determination of the stupendous advantages and savings which will surely follow the general electrification of the railroads; in fact, I think we can demonstrate that there is no other way known to us by which the railroad problem facing the country can be as quickly and as cheaply solved as by electrification.

The solution of the railroad problem would also "kill two birds with one stone" by solving the fuel problem at the same time.

If it is a fact, as has been stated, that the steam railroads of the country have failed to keep pace with the country's productive capacity—the increased output of manufacturing industries, the extension of agriculture and other demands for transportation —it is obvious that if the country is to go ahead, the railroad transportation problem must be solved and it must be solved at the earliest possible date. It becomes a matter of national importance that the best solution should be reached in the shortest possible time. That solution is best which will give the greatest amount of transportation over existing tracks, in the most reliable manner, and if possible, at the lowest operating cost. We electrical engineers are confident that we can make good our claim that the best solution is to be found in a general electrification of the railroads. That such a solution would be of great advantage to our profession and to our industry is important, although not as important as the great advantage which it would be to our country, freeing it as it would from the present threatened paralysis of business, possibility of untold human suffering and incalculable financial loss. It should give us courage and optimism for the future of our profession to contemplate the service which we may render in this direction, and which it seems to me is immediately at hand. It should arouse in all of us, and particularly in the younger engineers, an enthusiastic confidence in the present and future stability and value of our profession and of the electrical industry. It should satisfy the young engineer that the opportunity for him to render important service is as real and great to-day as it has been in the past for those of us who have seen and participated in the marvelous growth of the industry up to the present time.

We would not be justified in being so confident of the benefits of electrification of railroads if every element in the problem had not been solved in a thoroughly practical manner. The electric generating power stations, operated either by water or by steam turbines, have reached the highest degree of perfection, efficiency and reliability, while the transmission of electricity over long distances, with reliability, has become a commonplace. Electric locomotives capable of hauling the heaviest trains at the highest speeds, up and down the heaviest grades, have been built and found in practical operation to meet every requirement of an exacting service. There is, therefore, no element of uncertainty nothing experimental or problematical, which should cause us to hesitate in pressing our claims upon the attention of the country.

Electrification of railroads has progressed with relative slowness during these many years, waiting upon the development and perfection of all of the processes of generation and transmission and of the perfection of the electric locomotive itself. When all these elements had been perfected, as they now have been for several years, the railroads found themselves without the necessary capital to make the investment.

I realize that the task of electrifying all of the steam railroads of the country is one of tremendous proportions. It would require under the best of conditions many years to complete and demand the expenditure of billions of dollars.

The country, however, has clearly outgrown its railway facilities and it would require, in any event, the expenditure of billions of dollars and many years of time to bring the transportation facilities up to the country's requirements.

It is not necessary that electrification should be universal in order to obtain much of its benefits. It is probable that the most serious limitations of our transportation system, at least in so far as the supply of coal is concerned, is to be found in the mountainous districts and it is precisely in such situations that electrification has demonstrated its greatest value. Electrification of a railroad in a mountainous district will in the worst cases enable double the amount of traffic to be moved over existing tracks and grades.

If a general scheme of electrification were decided upon, the natural procedure would be, therefore, to electrify those portions of the steam railroads which will show the greatest results and give the greatest relief from existing conjestion. Electrification of such sections of the steam railroads would have an immediate and beneficial effect upon the entire transportation system of the country and it is our belief that electrification offers the quickest, best and most efficient solution that is to be obtained.

It may be said that the present is not a propitious time in which to deflect any of the country's money into railroad electrification. I think that in spite of the enormous advantages of which I have spoken, we would be inclined to agree with such a point of view if it were not for the recent unpleasant demonstration of the failure of our railroad transportation systems to meet the demands which have been placed upon them by the industries, aggravated it is true by the war conditions and also by the unkindness of the weather.

After all, the question for the country to decide is whether we

dare to limp along with the present conditions of restricted production, due to limited transportation, at a time when the world demands and expects from us the greatest possible increase in our efficiency and total production.

What assurance have we that the present conditions are temporary, and even if they improve as they surely shall with the coming of warm weather, what are we going to do next winter? Of course, even if we should start electrification at once, we could not have all our railroads electrified by next winter but we could have a good start, and as Sherman said about the resumption of specie payments—"The way to resume is to resume," so "The way to electrify is to electrify."

To be presented at the 338th meeting of the American Institute of Electrical Engineers, Cleveland, Ohio, March 8, 1918.

DESIGN OF UNDERGROUND DISTRIBUTION FOR ELECTRIC LIGHT AND POWER SYSTEMS

BY G. J. NEWTON

ABSTRACT OF PAPER

In a previous paper presented at the 10th Annual Convention of the Association of Iron and Steel Electrical Engineers the author made some suggestions, based on many years experience in designing underground distribution systems, for the guidance of engineers interested in this class of work.

The previous article treated the subject only in a general manner; the object of this article is to show each step necessary in the design of an underground distribution system, such as is usually required in a medium size city.

No two systems are entirely alike. The operating conditions and municipal requirements are different in every locality, it is impossible, therefore, to make any definite rules that will apply under all conditions.

By assuming the average conditions met with in the smaller cities it is possible to show the fundamental principles of handling this work in a systematic manner. While systems may, and do, differ, still it is possible to design a system for any type of distribution if these principles are followed.

Where costs are given they are based on normal conditions and should not be taken as being the present costs, they are used simply for comparison however and will be of value in that manner only, and if treated as percentage difference will apply under any reasonable conditions.

Owing to lack of space no tables have been printed in this article as they can be found in electrical handbooks.

IN ORDER to show each step in the design of an underground distribution system in the business section of a medium size city, it will be assumed that the present system consists of 110-220-volt single-phase lighting, 220-volt three-phase power and a street lighting system, as this, or some similar arrangement is commonly met with.

In order intelligently to design a system of underground distribution it is necessary to have the following information:

1. The lighting and power load in each building and the most suitable place to terminate the service cables, due regard being given to the present feeding point, so that the new system of

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secondary mains can be located to the best advantage with the least changing of the present inside wiring.

2. Location of all street lights that are to be connected to the new system of distribution.

3. Voltage of the lights and motors that are to be supplied from the new system.

4. Location of pipes, sewers, foreign conduit systems and all other sub-surface obstructions in the streets where it is proposed to locate the new conduit system.

5. Kind of pavement on each street.

6. An accurate map of the proposed underground district drawn to a scale that will permit showing the details of property lines, curbs etc.

7. A copy of all city ordinances governing this class of work.

8. Cost of labor, teams, paving, material and equipment required to install the system.

The design of an underground system is not a difficult matter if handled in a systematic manner; there are however, a few general rules that should be adhered to, as far as possible, to get the best results.

1. Design the cable system to give the most economical, efficient and reliable service and then lay out the conduit to serve that arrangement.

2. Try to foresee, and provide facilities for meeting every kind of trouble that is liable to occur. As far as possible provide two sources of supply for every distribution center, particularly those located in important districts.

3. Remember that the ultimate value of the system is not its first cost; an improperly designed and installed system will never give satisfaction and will cost more for changes and additions in the end.

4. Use the best material and experienced workmen; there is no branch of an electrical undertaking where inferior material and poor work will give greater trouble than in an underground system.

Before taking up the actual design it will be well to consider the selection of cables to be used for the various systems as this must be kept in mind while making the design.

Feeders. Assuming that the station is equipped with three-phase generators and that the lighting load is balanced on all three phases, it will be advisable to select uniform sizes of cables for the light and power feeders, in order to reduce the amount of

emergency cable required and also to standardize the switches and other equipment.

Primary Feeders run direct from the station to centers of distribution with few or no taps on them; they are installed in the lower or trunk ducts and are not liable to mechanical injury after being installed. These feeders receive the greatest benefit from the diversity factor, therefore it is not necessary to provide a great amount of reserve capacity as other feeders can be added as the demand increases.

Secondary Feeders run from the centers of distribution to the various transformers and are also in the lower ducts; these cables receive less benefit from the diversity factor than the primary feeders therefore they should have a little more reserve capacity.

For the system under consideration both of these classes of cables should be three-conductor cables. They can be either paper or varnished cambric insulated. If paper is used it will be necessary to splice rubber or varnished cambric insulated cable tails on it wherever they enter equipment. Personally I prefer varnished cambric or varnished cloth insulated cables for all distribution work, particularly in the smaller cities where usually the cable department is very limited.

Secondary Mains. The secondary mains for the power system will be three-conductor cables as they supply only three-phase power and will have three-conductor services spliced to them.

The secondary mains for the lighting system will have to be large, as that load is single-phase, as far as the secondary distribution is concerned, and next to the service cables they receive the least benefit from the diversity factor.

If three-conductor cable was used there would be a considerable reduction in the carrying capacity over single-conductor cables (25 per cent) also it would not be possible to take more than about two services out of each splice; this would increase the number of service boxes required and add considerably to the cost of the system.

The neutral of the 110-220-volt lighting system should be grounded at every transformer vault, and therefore unless there are some exceptional conditions, such as excessive electrolysis, there is no reason why the neutral can not be a bare copper stranded cable, and by using two single-conductor cables for the "outers" it will be possible to get the greatest benefit from the carrying capacity of the cables installed.

Considering the fact that there is no way of providing any

emergency facilities for the secondary mains and that they receive the least benefit from the diversity factor, and are cut at frequent intervals for splicing the services, it is evident that they are the most important link in the distribution system. Trouble on a secondary main is very liable to interrupt service to every consumer spliced to it, and requires considerable time and expense to repair; therefore these cables should be given considerable excess carrying capacity to provide for future growth, and have varnished cloth or cambric insulation. (Except in special cases it is unnecessary to use rubber insulated cable on any part of a distribution system, except to enter equipment as mentioned previously.)

The single-conductor secondary mains will permit four service cables being taken out of each splice if necessary.

It is a good plan when installing secondary mains, particularly when there is a heavy load about the center of a block, to make a loop service of the main, instead of running service cables into the building, as this permits sectionalizing the main in case of trouble and reducing the number of consumers out of service. This arrangement also reduces the time required to locate trouble on a main.

Service Cables. The service cables for the power system should be three-conductor, but those for the lighting system should be single-conductor. It is advisable to install three service cables for every consumer where there is any liability of the load being over one kw. and if three cables are taken to all consumers it will be an easy matter to keep the 110-220 volt load balanced without the necessity of opening splices to make changes.

Laterals. The lighting and power services should be installed in separate pipes, and in the business district of a city it is a good plan to install two laterals to all consumers when the system is installed. When fibre conduit is used for the laterals, as is generally the case, the cost of installing the additional duct is very small as there is practically no additional excavation or paving required and very little additional concrete.

Service Boxes. Service boxes should be about three by four feet, and located at the most convenient points to permit the services entering the buildings, they should be spaced so that the services are not unreasonably long and that not more than four services are taken out of each box.

Keeping the above facts in mind we can now proceed with the design of the system.

Load Map

Fig. 1 shows the load map. Each block is numbered for future reference and the building lines are shown (it is not necessary to show the individual stores in a building as all of the consumers in a building should be supplied from one service in order to save cable and get the benefit of the diversity factor between consumers). The house numbers should be given but are omitted from this plan to avoid confusion.

The point where the service is to enter the building is shown,

TABLE I
LOAD RECORD BY STREETS

Street	From	To	Light	Power	Total
Ave. A.	First St.	Second St.	88.0	98.0	186.0
" "	Second "	Third "	93.0	57.0	150.0
" "	Third "	Fourth "	53.0	33.0	86.0
" "	Fourth "	Fifth "	110.0	41.0	151.0
" "	Fifth "	Sixth "	98.0	23.5	121.5
Ave. B.	First St.	Second St.	69.0	36.5	105.5
" "	Second "	Third "	93.5	45.0	138.5
" "	Third "	Fourth "	197.0	102.0	299.0
" "	Fourth "	Fifth "	178.0	83.0	261.0
" "	Fifth "	Sixth "	93.0	58.0	151.0
Ave. C.	First St.	Second St.	44.0	32.0	76.0
" "	Second "	Third "	48.5	20.5	69.0
" "	Third "	Fourth "	57.5	20.0	77.5
" "	Fourth "	Fifth "	51.0	14.5	65.5
" "	Fifth "	Sixth "	40.0	32.0	72.0
1st St.	River	Ave. C	138.5	76.0	214.5
2nd "	"	" "	139.0	77.0	216.0
3rd "	"	" "	120.5	62.0	182.5
4th "	"	" "	214.0	62.0	276.0
5th "	"	" "	128.0	31.0	159.0
6th "	"	" "	109.0	25.5	134.5
Big Store			65.0	150.0	215.0
			2227.5	1179.5	3407.0

Streets 12,000 ft., or an average of 284 kw. per 1000 ft.

and the loads are marked on the plan facing the street from which they are to be supplied. While it is advisable to mark the most desirable location for the laterals still it is frequently necessary to select a less desirable location in order to reduce the amount of conduit or cable; as far as possible however, it is advisable to adopt a uniform method of installing the laterals as this permits standard construction and reduces the cost.

Having completed the load map the next step is to tabulate it by streets and blocks, as shown in Table 1. Referring to this

table, it is seen that the lighting load is 2227.5 kw. and the power load is 1179.5, or a total of 3407 kw. to be supplied as follows:

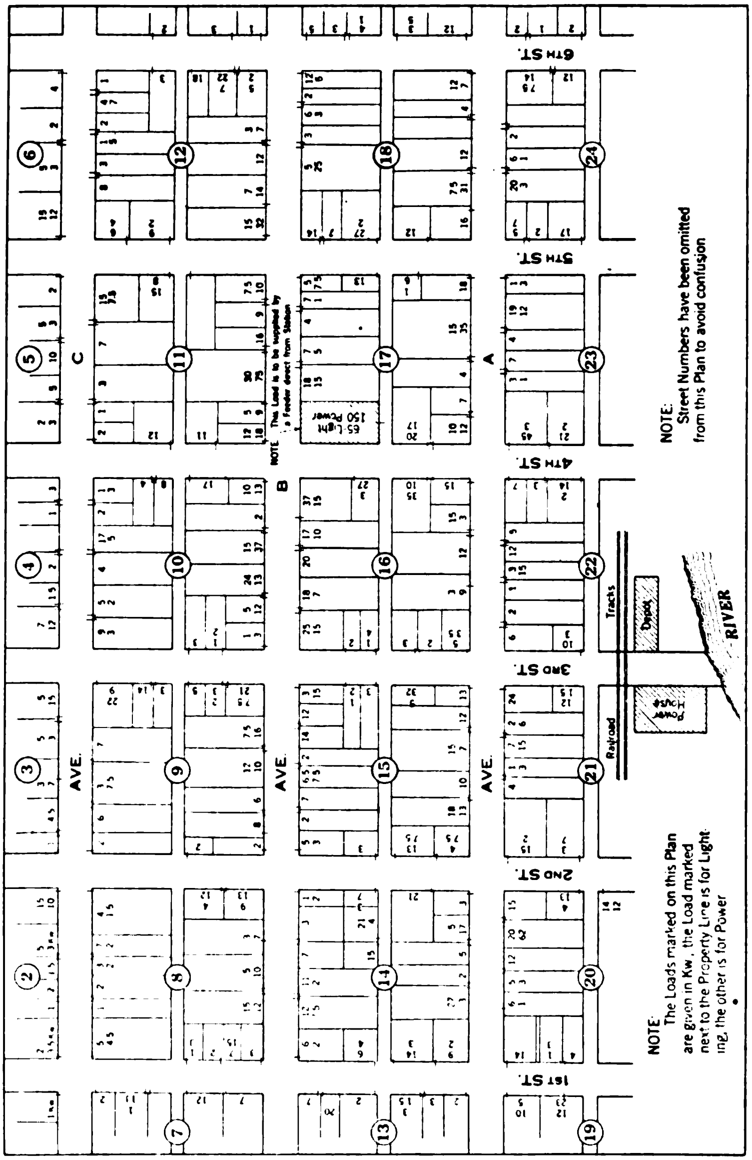

FIG. 1—LOAD MAP

Lighting system a-c. 110-220 volts single-phase three-wire.
Power load a-c. 220 volts, three-phase.
Street light system, a-c. 5.5 amperes, series.

It is always advisable to show the location of the street lights on the load map for, assuming that *all* wires in the district must be placed underground, it is evident that there must be conduit to every lamp and by laying out a rough plan of that system, or circuit, a general idea of the conduit arrangement can be determined. As the location of the street lights is determined by the city authorities it is seldom possible to change their location and by knowing where the conduit must be placed for street lights it will frequently permit a saving in conduit in other localities by changing the secondary arrangement of some of the consumers.

Owing to the fact that conduit systems are very expensive there is a great tendency to select streets having the cheapest pavement in which to install the conduit. While it is desirable to do work as cheaply as possible, still there is more than the first cost to be considered. Where a conduit system is used for feeders or high-tension systems exclusively, and there is no distribution from it, there is no objection to selecting such routes as will permit the conduit being installed as cheaply as possible.

Where a conduit system is installed for distribution to consumers the location should be governed entirely by the best method of reaching the various buildings regardless of the kind of pavement.

Series Street Light System

Fig. 2 shows the series street light system. There are 51 72-volt arc lights and 15 20-volt incandescent lights on the circuit in this district, the approximate voltage of the system being about 4000. As No. 6 6000-volt cable is standard for this class of service it is advisable to use it for all circuits of this system.

As the location of the lamps is determined by the city authorities, and the circuit must reach every lamp, there are only two things to consider; first to use as little cable as possible and second to arrange the circuit so that it will be possible to sectionalize it in case of necessity. The arrangement, shown in Fig. 2, permits sectionalizing the circuit at three points, in case of trouble, without any unnecessary cable being used.

It is doubtful if a circuit as small as this one would require any sectionalizing facilities; however the arrangement is shown here for illustration.

Assuming that the arc lights on the street are to be placed on new iron poles and the incandescent lights in the alleys on wooden poles the best arrangement for the cable would be to use either

paper- or varnished-cloth-insulated cable for the main cable and rubber-insulated cable for the pole ends.

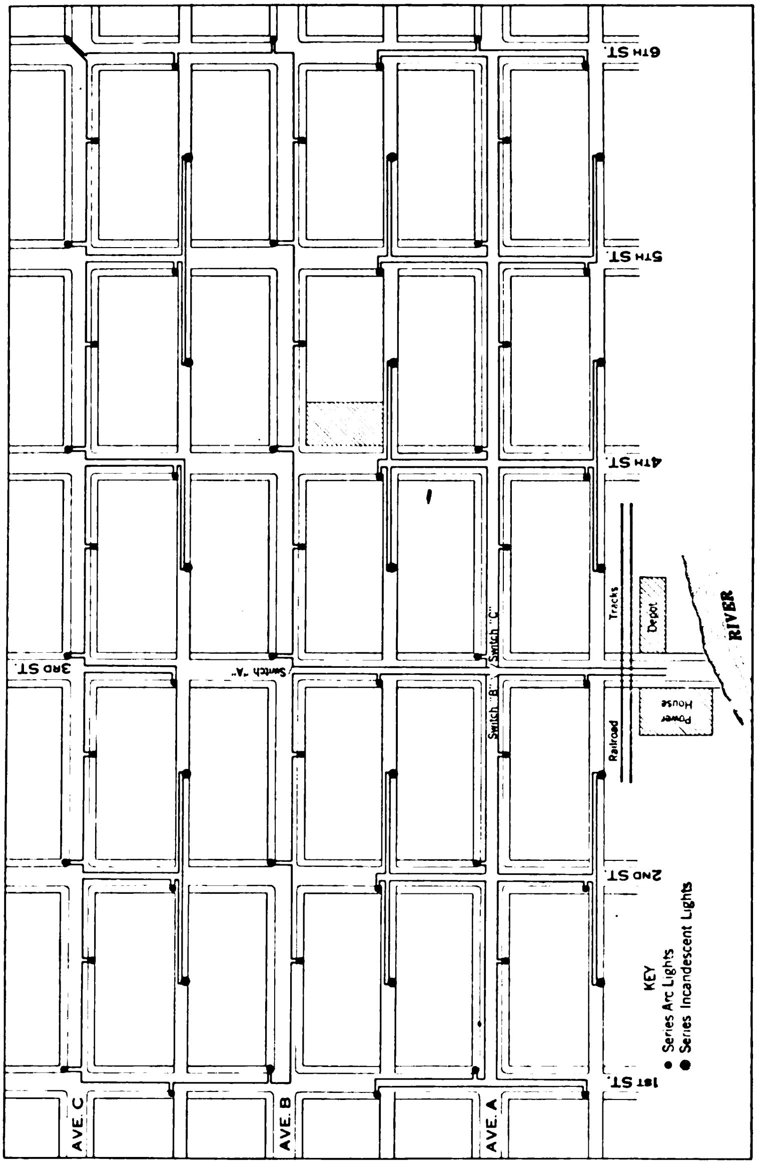

FIG. 2—SERIES STREET LIGHT SYSTEM

Frequently the pole end cable is run from the manhole, or handhole, up the pole to the lamp, this is a mistake, and a better plan is to terminate the pole end cable in series cut-outs mounted

in the base of the pole and run insulated wire from this point up to the lamp, this permits the lamps being cut off from the circuit easily in case it is necessary to test the cable for trouble at any time and also saves considerable cable.

Referring to the figure, it is seen that there are many places where two-conductor cable could be used to advantage and in such cases the engineer must decide whether to use all single-conductor cable or two-conductor where possible. The difference in cost will be very small and undoubtedly the single conductor cable would give the most reliable service, and as two cables can easily be drawn in one duct there is no saving in duct space by using the two conductor cable.

If two-conductor cable is used it should be made in the round form and not figure "8" or flat, as it is practically impossible to train the flat cable without kinking it, and this will cause damage, particularly with paper insulated cable as small as this type of cable would be.

Assuming that the cable has to reach the 15 lights in the alleys and that the alleys are paved, and that, with the exception of Block 14, it is unnecessary to run any secondary mains in the alleys, the question may arise as to the advisability of installing steel armored cable laid directly in the ground for these extensions.

If the alleys are paved there will be very little difference in cost between the two systems, possibly a saving of 25 per cent. This is too small a saving to warrant purchasing and keeping in stock the extra type of cable. The best plan would be to install a single fibre duct to all of the lamp poles in the alleys. Armored cable should never be installed under permanent pavement, particularly in the business section of a city.

In making the estimate for this system it will be assumed that No. 6 varnished cambric insulated cable, for 6000 volts, is used, terminating in cutouts in the base of the iron poles and in cutouts mounted on the wooden poles above the lateral pipe.

Owing to the location of the street lights the cable for this system will have to be installed in one of the upper, or distribution, ducts so that it can be taken out at any handhole for future lights that may be installed. If there were other arc circuits, feeding other districts, they would of course be installed in the lower or trunk ducts, such cables could be paper insulated as they would have no taps on them until brought out at the pole from which they were to run aerial.

While a series arc circuit has been shown in this system it is practically certain that in this district the streets, or the principal ones at least, would have an ornamental system, these systems vary so greatly that it was not thought advisable to show one on these plans. If an ornamental system is required in this district it will be found that there is a spare duct in the upper tier of conduit that is available.

While the series arc circuit has been designed first, in this case it does not particularly aid the design of the secondary layout as the load in the district is so heavy and so well distributed along the streets that it is evident that mains will have to be placed along each street; still this method is usually advisable.

Center of Distribution

From a distribution point of view, the ideal location for a station would be at the center of the load that it was to supply, but unfortunately such a location is seldom possible or advisable owing to the value of real estate and lack of facilities for receiving and storing fuel. In the case under consideration the power house is already located and the distribution must be designed from that point. It is, therefore, necessary to find where the center of the load is, or if it is too large for one feeder to supply, the load must be divided and separate centers located.

Where the load is large enough to require two or more feeders it should be divided as equally as possible so as to permit using a uniform size of cable for all the feeders. If there is any section where the load is liable to increase rapidly this fact should be considered in locating the center of distribution and assumed to exist, and feeder capacity allowed for it.

Fig. 3 shows the three-phase power arranged for locating the centers of distribution. Ordinarily it is sufficient to assume that the entire load in a block is concentrated at the center of the block, for the purpose of illustration in this case the load has been shown on each side of each street, and the loads are marked facing the streets from which it will be supplied. (This system of marking is carried out on all of the illustrations.)

Referring to Table 1, the power load is given as 1179.5 kw., this includes the 150 kw. that is in the store at 4th Street and Ave. B. which is to be supplied by a separate feeder from the station, leaving 1029.5 kw. (say 1030 kw.) to be supplied by the regular feeders. This is too large a load to supply with one feeder, and as 2/0 three-conductor cable will supply 558 kw.

at 2200 volts, it is advisable to use two feeders of that size and locate two centers of distribution, each having about 515 kw.

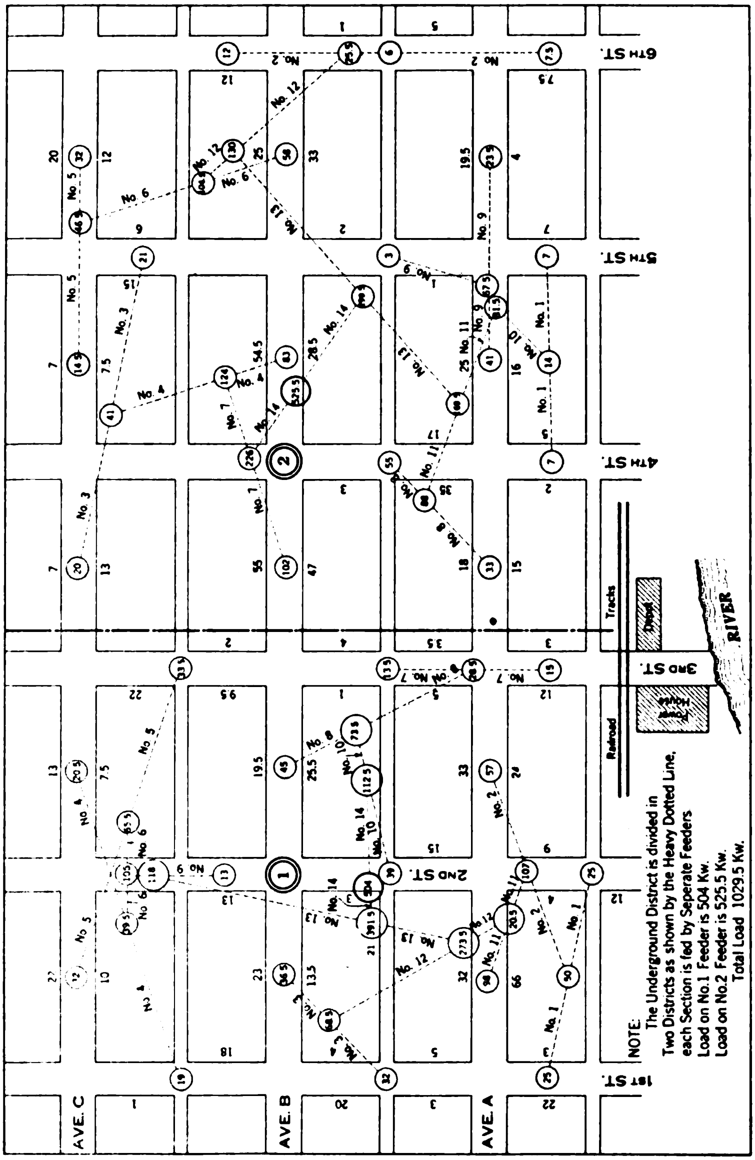

FIG. 3—CENTER OF DISTRIBUTION

or half the total load. Later the actual size of feeders can be calculated, considering the power and diversity factors.

Referring to Fig. 3, the heavy broken line running north and

south divides the load as follows: Feeder No. 1, 504 kw., feeder No. 2, 526 kw. (It is always best to try several ways of dividing the load and then select the one giving the best results.)

The loads marked in the small circles in the streets is the sum of the loads in the blocks facing those streets and the circles are located approximately where these centers would be.

The lines joining the various loads are numbered from 1 up to 14, for feeder No. 1, and gives a result of 504 kw., and the large circle marked 504 kw. is the proper point from which to supply this district.

As it is very probable that the transformers for supplying the lighting load will be located at street intersections it is safe to assume this centre of distribution as being at the nearest corner, or Second Street and Avenue B. Center No. 2 is calculated in the same manner.

The order in which the loads were taken is to avoid confusion; the work can be simplified greatly by combining loads of equal size whenever possible.

2200-Volt Three-Phase Power Feeders

Fig. 4 shows the power load marked in each block and the two power feeders terminating at the centers of distribution, that were located on Fig. 3. In order to provide for an emergency there is a spare feeder shown laid out in such a manner that the load on either of the regular feeders can be transferred to the emergency feeder in case of necessity. The spare feeder is also arranged to act as an emergency feeder to the large store at 4th Street and Avenue B., should its regular feeder fail.

As far as possible each feeder is run over a separate route. In a small district, such as the one under consideration, separate routes from the station are not warranted and the next best method is to separate the feeders as soon after they leave the station as possible.

Having decided the route of the feeders the next step is to calculate the size of cable to use. The power load is constantly changing and it is impossible to tell what the actual maximum demand will be for any group of consumers and all that can be done is to assume certain conditions as a basis for the calculations.

The maximum demand of a group of consumers is less than the sum of the several maxima, likewise the sum of several groups is less than the sum of their maxima, therefore, in a distribution system the primary feeders will receive the greatest benefit from

the diversity factor, the secondary feeders less benefit, and the secondary mains the least benefit.

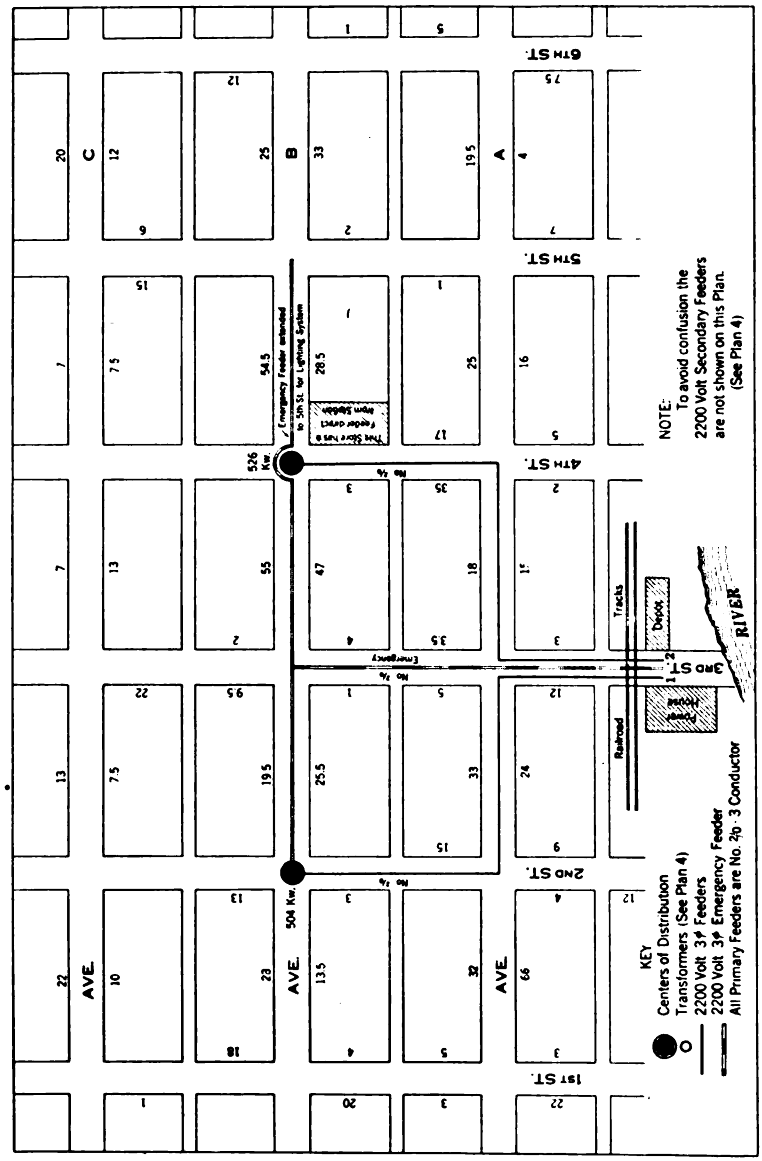

FIG. 4—PRIMARY POWER FEEDERS—2200-VOLT—THREE-PHASE

Assuming that the maximum demand will vary from 60 to 80 per cent of the connected load on various parts of the system, the feeders and mains can be calculated as follows:

Primary feeders, 60 per cent of the connected load.
Secondary feeders, 70 per cent of the connected load.
Secondary mains, 80 per cent of the connected load.

Where definite knowledge of the demand is known other figures should be substituted for those given here.

Referring to Fig. 5, it will be seen that there are 127 consumers having a total connected load of 1030 kw., or an average of 8.1 kw. each. This is rather high for a district such as is under consideration, and it is evident that the demand for power is fairly high in this district. As the system is used exclusively for power the power factor will be about 0.8 and for the feeders, take 60 per cent as the demand factors, as the load on each feeder is practically the same it is only necessary to calculate one feeder.

TABLE II—CARRYING CAPACITY OF MULTI-CONDUCTOR CABLES. SAFE CURRENT IN AMPERES

Size	1 Conductor	2 Conductor	3 Conductor
8	45	39	34
6	64	56	48
4	91	79	68
2	125	109	94
0	168	146	126
00	195	170	146
000	225	196	169
0000	260	226	195
250,000	293	255	220

NOTE: This table is based on information contained in the Standard Underground Co's. Handbook, taking the carrying capacity of single-conductor cable as 100% and using 87% for two-conductor cable and 75% for three-conductor cable for continuous operation at a temperature not exceeding 150 deg. fahr..

EXAMPLE.

Feeder No. 2

Connected load.................................... 526.0 kw.
Power factor.. 80 per cent
Demand factor...................................... 60 per cent
Allow for growth 25 per cent of the connected load.

$$\frac{526 \text{ kw.}}{0.8 \text{ power factor}} = 658 \text{ kw.}$$

658 × 0.6 = 395 kw. present actual load.
526 × 0.25 = 132 " allowance for growth.

527 " total load for which to provide feeder capacity.

$$I = \frac{\text{kw.} \times 1000}{E \times 1.73} = \frac{527 \times 1000}{2200 \times 1.73} = 138 \text{ amperes}$$

Referring to Table II under three-conductor cable, it is seen that 2/0 cable will carry 146 amperes, therefore this is the proper size to use, and this checks the first selection of feeder size in calculating the centre of distribution.

Three-conductor 2/0 cable will deliver 558 kw. at 2200 volts, which is about 6 per cent more than the present connected load on the feeder, or 41 per cent more than the estimated load of 395 kw. Three-conductor 1/0 cable will deliver 481 kw. at 2200 volts and while this would supply the present estimated load, it would leave a very small reserve capacity, particularly as the estimated load is based on assumed conditions.

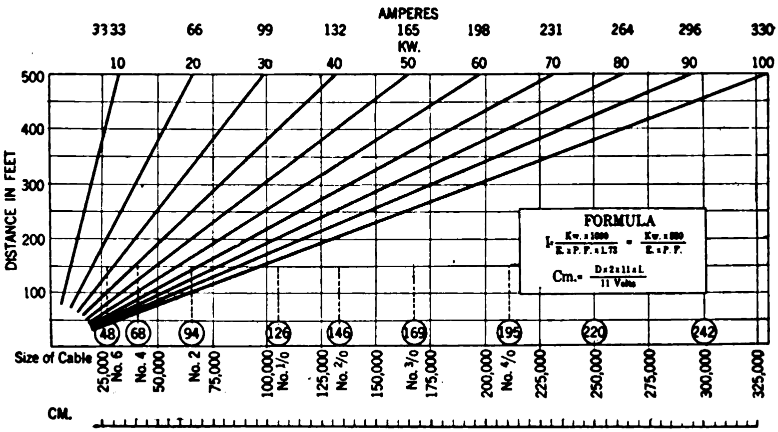

CHART I—LOAD IN KW.-THREE-PHASE–220 VOLTS—80 PER CENT POWER FACTOR—5 PER CENT LOST = 11 VOLTS

This chart is for use in determining the size of the three-phase power mains to save calculating each one—in using it care must be taken to see that the cable will carry the amperes that the load requires

It is in a case like this that the engineer must be guided by his personal knowledge of the conditions, and as cost is frequently the deciding factor we can make an estimate for each size of feeder.

Feeder No. 1	1000 ft.
Feeder No. 2	1000 ft.
Emergency Feeder	1400 ft.
Total	3400 ft.

The following prices are approximately correct for three-conductor, varnished-cambric-insulated, lead-covered cables for 2300 volts working pressure, with copper at 16 cents per lb.

Size	Price per 1000 ft.
No. 4 cable......	$220.00
" 2 "........	300.00
" 1/0 "........	390.00
" 2/0 "........	450.00
" 4/0 "........	635.00

No. 2/0 cable 1400 ft. at $450.00...........	$1530.00
" 1/0 " 1400 " " 390.00...........	1326.00
	$ 204.00

This is a very small amount to save considering that the duct space and cost of installation are practically the same for either cable and the additional security and reserve capacity would justify the use of the 2/0 cable in this case.

Before laying out the secondary feeders it is advisable to design the secondary mains, as the location and size of the transformers will depend on their arrangement.

220-Volt Three-Phase Power Mains

Fig. 5 shows the arrangement of the 220-volt three-phase power mains laid out so as to supply all of the power consumers. It will be noticed that some of the mains only extend far enough to supply the load on certain streets and are not continued to the adjacent manhole. This is a good plan to try at first and calculate the size of cable required for each main, and where the cable will be too large the main can then be extended to the next manhole so that it will complete the network and be supplied from each end.

The two feeder districts are kept separate, but where mains from one feeder extend to a manhole of the other district (as at Ave. B. and Third Street) they can be tied together in a suitable junction box so that they are supplied from both ends. The main will form a loop in such cases.

In calculating the size of cable to use for the mains it must be remembered that all of the services are spliced directly to the mains, and the replacement of a main is a very expensive matter, the old cable removed, being in short lengths, is of little value except for junk.

While it is certain that all of the motors will not be operated at the same time still the mains must be of sufficient size to maintain the voltage without excessive drop under the worst

condition. Where there is a reasonable prospect that the load will increase it is advisable to install mains large enough to provide for this increase.

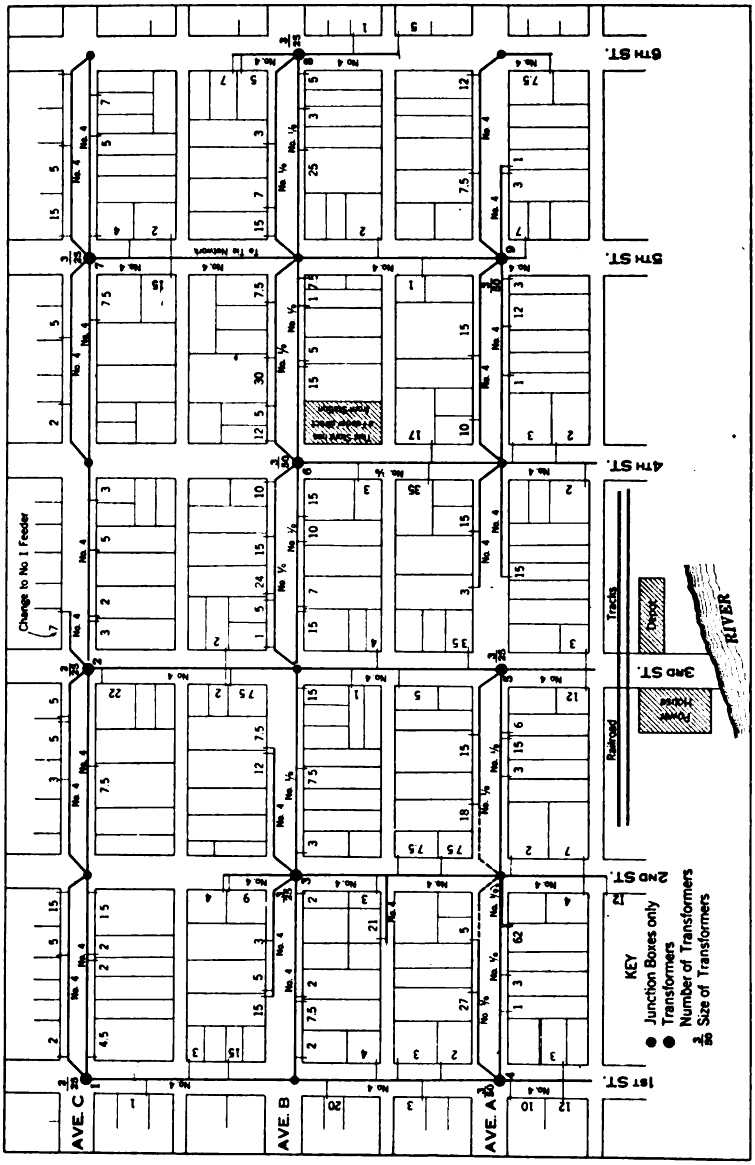

Fig. 5—220-Volt—Three-Phase—Power Mains

To illustrate the method of calculating the size of mains, in Fig. 5, take the two blocks on Avenue C. from First to Third

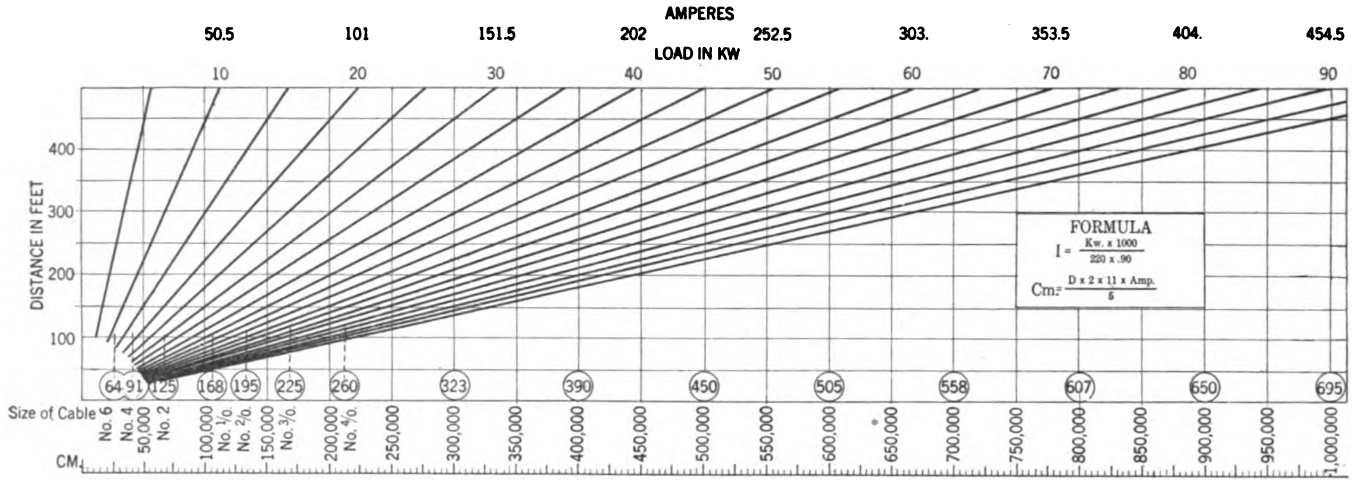

CHART II—220-VOLT—SINGLE-PHASE LIGHTING MAINS—90 PER CENT POWER FACTOR—2 PER CENT DROP = 5 VOLTS

This chart is for use in determining the size of the lighting mains to save calculating each one—care must be used to see that the carrying capacity of the cable given is sufficient for the load.

Take the load in kw.—follow the diagonal down to the proper distance and under this point on the scale will be found the size of cable.

Street, which has mains on both sides of the street and is supplied from transformers at each end.

Allowing 5 per cent drop, 0.8 power factor and assuming that 80 per cent of the motor load is to be operated at the same time, the 0.8 power factor, and the 80 per cent demand factor will, in this case, counterbalance each other and by taking the connected load as the amount to be provided for we will be allowing for these conditions.

First take the load in each block separately and assume that transformer No. 1 supplies the 22 kw. in block No. 1, and that transformer No. 2 supplies the 13 kw. in block No. 2; the center of the 22-kw. load is about 310 ft. from transformer No. 1 and the center of the 13-kw. load is 165 ft. from transformer No. 2.

EXAMPLE

$$I = \frac{\text{kw.} \times 1000}{E \times 1.73} = \frac{\text{kw.} \times 580}{E}$$

$$I = \frac{22 \times 580}{220} = \frac{12{,}760}{220} = 58 \text{ amperes.}$$

And for the size of cable,

$$\text{Cir. Mils.} = \frac{\text{ft.} \times 2 \times 11 \times \text{amperes}}{\text{volts lost}}$$

$$= \frac{310 \times 2 \times 11 \times 58}{11} = 35{,}960.$$

The next larger size is No. 4 or 41,740 cir. mils, and from Table II, under three-conductor cable, it is found that No. 4 will carry 68 amperes so this size will carry the present load but provide little spare capacity for growth. For the present, assume that No. 4 will be used here and proceed in the same manner to calculate the size for the 13-kw. load. The result is 11,220 cir. mils, or between No. 9 and No. 10 wire, but as it is not advisable to use anything smaller than No. 4 for secondary mains it will be assumed that this section will be No. 4 also. So far nothing has been allowed for growth but the mains would extend from each transformer bank far enough to supply all of the loads. This arrangement could be used at first and later when the load demanded the two mains could be tied together with the following result.

The total load in the two blocks will be 22 + 13 = 35 kw. which is assumed to be located at the center, or 400 ft. from each end of the main.

Total load, 35 kw.

Supplied from each end, 17.5 kw. (say 18 kw.).

$$I = \frac{18 \times 580}{220} = 48 \text{ amperes.}$$

$$\text{Cir. mils} = \frac{400 \text{ ft.} \times 2 \times 11 \times 48}{11} = 38{,}400 \text{ (Use No. 4).}$$

This will give a continuous main and would provide for a very considerable increase in load as the entire load is not concentrated at the center of the main, as assumed.

The assumption of 80 per cent demand factor is undoubtedly high, for this class of service and is only used here as an example of the method of calculation. All of the other mains are calculated in the same manner.

The mains should all be calculated and marked in pencil on the plan temporarily, after which it is advisable to select a few standard sizes and use them throughout the system. If the power and lighting cables are all marked temporarily at first it is frequently possible to standardize both systems with a few different sizes of cable.

In calculating the size of mains on Avenue A, from First to Third Street, it was found advisable to extend two of the mains as shown by the dotted lines to permit using No. 1/0 cable for all of the mains in those two blocks and assuming that the total load was concentrated at the manhole at Avenue A and Second Street, which is the worst condition that could occur in this section, the four No. 1/0 mains terminating there are ample to supply it.

The mains as laid out in Fig. 5 are of two sizes, No. 4 and No. 1/0, and these sizes are very suitable as probably with the addition of some three-conductor No. 6 cable, for small services, all of the mains and services can be installed with three sizes of cable.

The consumer service cables will average about 50 ft. each and the loads vary from 1 to 60 kw. The drop in the services should not be more than 1 per cent, or 2 volts, and the full connected load should be provided for to take care of the extra current required for starting the motors.

The services can be divided into three groups as follows:

0 to 10 kw.	Use No.	6,	three-conductor cable.
11 " 20 "	" "	4,	" " "
21 " 40 "	" "	1/0,	" " "

Where the load is over 40 kw. two service laterals can be installed if the operating conditions of the load demand it, and frequently the location of the motors is such that two services are desirable; a case of this kind is shown at Avenue A. and Second Street where two services are required and they are taken from separate mains.

The next operation is to determine the size of the transformers to install at the feeding points. Owing to the fact that the motor load is constantly changing it is a very difficult matter to determine the most economical size of transformers to install, while there are occasional heavy loads still the average load is considerably less.

It is not advisable to have a large variety of sizes as this makes it necessary to keep a large number of transformers on hand for emergency purposes. The best method is to decide on as few sizes as possible and use them in open delta where necessary on small loads.

It will be noticed that the transformers are spaced, and the mains laid out, so that a large increase in load can be taken care of by simply installing transformers at the intermediate manholes without the necessity of changing any of the mains; also at some points the mains can be extended to the next manhole to complete the network.

Following is a summary of the loads to be supplied at the various feeding points. Transformers No. 1 to No. 5 are supplied by feeder No. 1 and transformers No. 6 to No. 9 are supplied by feeders No. 2.

Location	Connected load	75 % of load	Number of transformers	Size of trans.	Total capacity
No. 1	51 kw.	38 kw.	2	25 kw.	50 kw.
" 2	61 "	46 "	2	25 "	50 "
" 3	118 "	88 "	3	25 "	75 "
" 4	175 "	131 "	3	50 "	150 "
" 5	105 "	79 "	3	25 "	75 "
" 6	212 "	159 "	3	50 "	150 "
" 7	84 "	63 "	3	25 "	75 "
" 8	76 "	57 "	3	25 "	75 "
" 9	150 "	112 "	3	50 "	150 "
		Total transformer capacity..........			850 kw.

The total power load was 1030 kw. which is equivalent to 1380 h. p., and as 60 per cent of the connected load was taken as

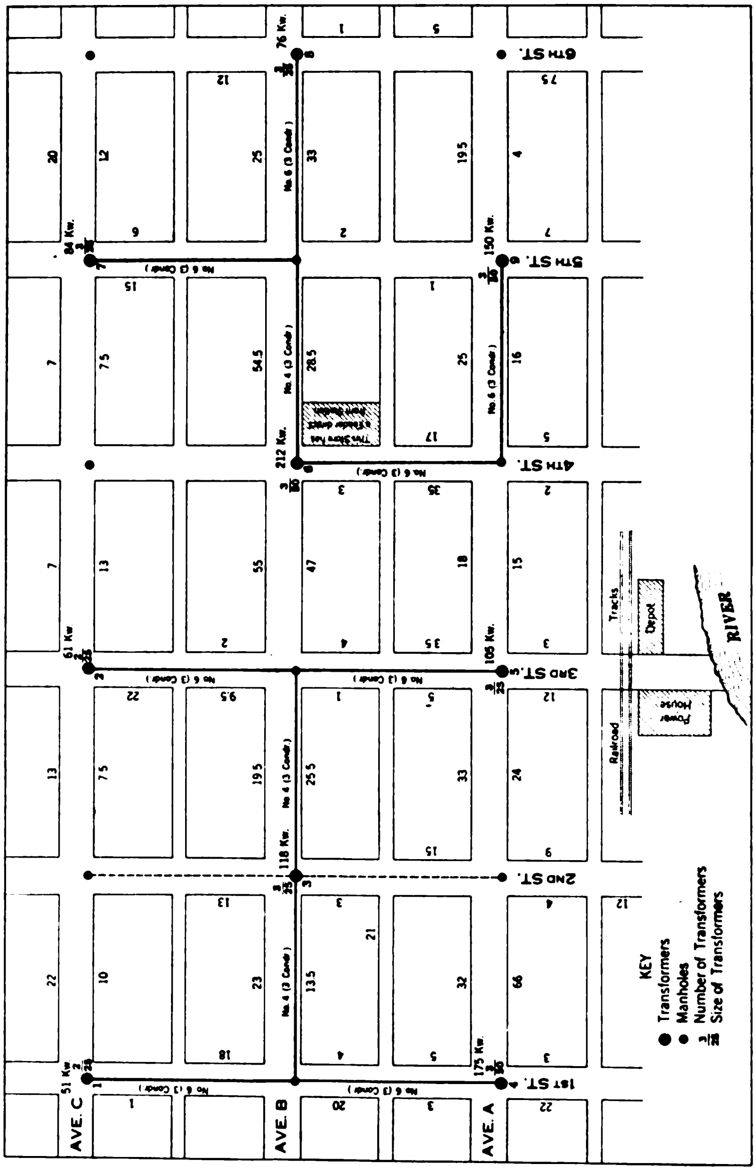

FIG. 6—SECONDARY POWER FEEDERS—2200-VOLT—THREE-PHASE

the maximum demand, or 828 h. p. the transformer capacity is a little over one kw. per h. p. which is the usual practise in power installations.

At feeding point No. 8, it would no doubt be advisable to start with two 25-kw. transformers in open delta as the load is only 57 kw. but for the purpose of this estimate it was considered best to be on the safe side.

It must be remembered that in designing a system and making an estimate of the cost, considerable allowance must be made for future conditions, as considerable time will undoubtedly elapse between the time that the designs are prepared and the installation of the system. The engineer also must not underestimate the cost.

2200-Volt Three-Phase Secondary Power Feeders

Fig. 6 shows the 2200-volt three-phase secondary power feeders that run from the centers of distribution to the various feeding points to supply the transformers and the low tension network as shown in Fig. 5.

The total connected load and the number and size of transformers is marked at each feeding point. In the original estimate for this system it was assumed that 70 per cent of the connected load would be the maximum demand on these feeders; the cable has been calculated on this basis, and there are only two sizes of cable used in this system.

From the manner in which the cables are installed it is evident that the capacity of the system can be greatly increased by simply running a few sections of No. 6 cable and installing additional transformers at intermediate vaults. This would make it necessary to alter the secondary network so as to maintain a balance but this would be simply a matter of changing connections in the junction boxes.

The largest single load at any point is at Avenue A. and First Street, 175 kw. and as 70 per cent of this, or 122.5 kw., is assumed to be the maximum demand and the three-conductor No. 6 cable will supply this.

On Avenue B., from Fifth to Sixth Street, No. 6 cable is specified, and while this is large enough for the present load it might be a good plan to use No. 4 here as this is on the main feeder that would have to be extended in case that the district was enlarged later.

This completes the power system and the next step is to consider the lighting system.

2200-Volt Three-Phase Lighting Feeders

Fig. 7 shows the 2200-volt three-phase lighting feeders. By reference to Table No. I the lighting load, exclusive of the big store, at Avenue B. and Fourth Street, is given as 2162 kw. This is the connected load in the district.

The demand of a group of residence consumers will vary from 15 per cent to 30 per cent of the connected load, and the average will probably be between 20 and 25 per cent. In commercial lighting the demand is much higher, as sign and window lights, as well as most of the store lights, are used at the same time. To offset this demand it is seldom that the lights in offices over stores are used when the store demand is at a maximum. The demand for commercial lighting will vary from 40 to 70 per cent of the connected load, depending on the nature of the district and the class of service, some nights the demand being much greater than other nights. The average demand for commercial lighting will be from 50 to 60 per cent of the connected load.

The district that is under consideration is the business district of a small city where practically all of the consumers are in the commercial class, it will therefore be assumed that the demand factor will be 60 per cent of the connected load.

The total connected load is 2162 kw., and 60 per cent is 1297 kw. (say 1300 kw.) and the first thing to decide is the proper size of feeders to use for this load. No. 1/0 will carry 481 kw. at 2200 volts, and it would require three such cables to carry the load and leave about 140 kw. spare capacity. This is about 11 per cent but as it is doubtful if the load could, in practice, be evenly divided between the three feeders this would be a small margin; also if possible it is a good plan to use the same size cables as was used for the power feeders so as to reduce the number of different sizes that must be kept on hand for emergency, and also permit using uniform equipment on the two systems.

The total amount of cable required for this system is about 3800 ft. and it would cost approximately as follows:

No. 2/0	3800 ft. at	$446.00 per M.	$1694.80
No. 1/0	3800 ft. at	386.00 per M.	1466.80
			$ 228.00

The saving in cost, by using No. 1/0 would not be enough to warrant carrying the additional size in stock, and considering that the duct space and cost of installation is the same for both

sizes, it is advisable to select No. 2/0 for all primary feeders for both systems.

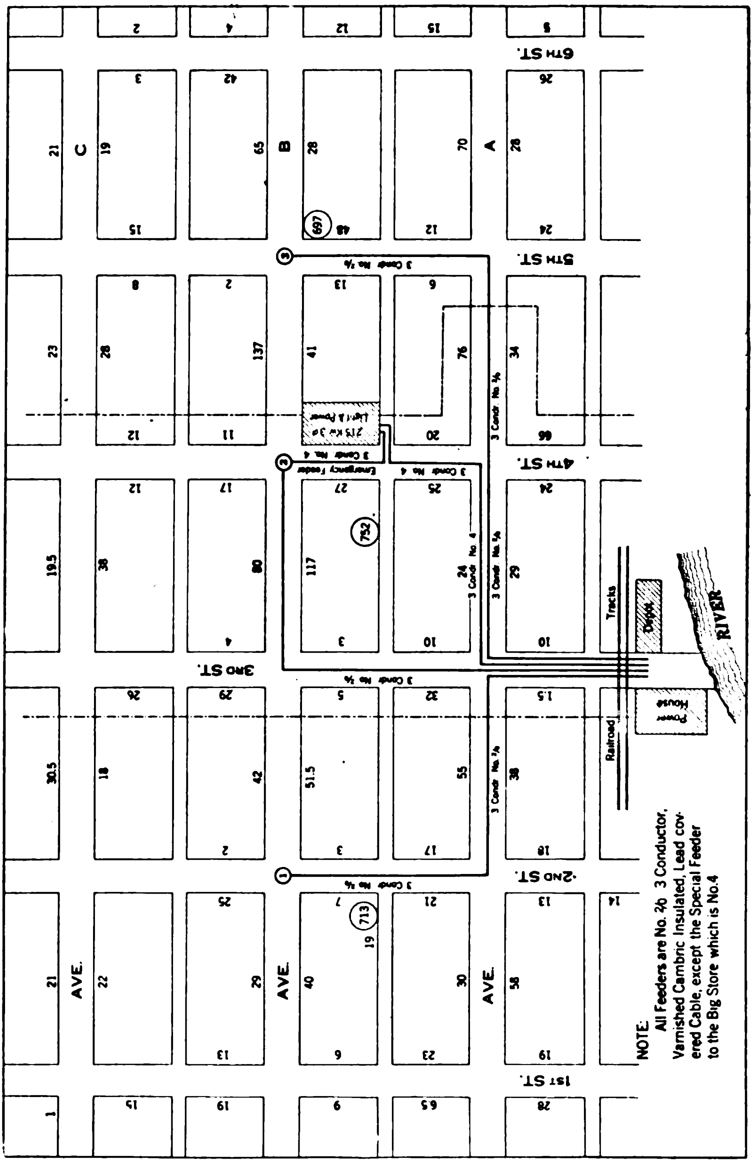

FIG. 7—2200-VOLT—THREE-PHASE LIGHTING FEEDERS

There is another point in favor of using No. 2/0 cable for this system, and that is, that the emergency feeder was of this size and by extending it from Fourth to Fifth Street on Avenue B.

(as shown by the dotted line in Fig. 4) it can be used as an emergency feeder for both systems.

By using three No. 2/0 feeders for this system the total feeder capacity will be 3 × 558 kw. or 1674 kw. This is 77 per cent of the connected load, which is rather high, but considering all of the conditions it is the most suitable arrangement.

The total load is 2162 kw., which will give 720 kw. for each feeder, and locating the centers of distribution in the same manner as was done for the power feeders the following result is obtained:

Feeder No. 1, 713 kw.
Feeder No. 2, 752 kw.
Feeder No. 3, 697 kw.

The three centers of distribution are marked approximately where they are calculated by assuming the loads to be concentrated at the points where they are marked. As none of the points are over 200 ft. from street corners, where the power transformers will be located, the same location will answer for this system and one vault will do for both systems. The dotted line divides the district into three sections showing the load to be supplied by each feeder.

The next point to consider is the feeder for the big store, which has to be supplied separately. The total load in the store is 215 kw. 100 kw. power, and 115 kw. lighting. There are three 75-kw. transformers in the store, and as No. 4 is the smallest size of cable used for feeders it is advisable to use that size for this feeder as it will safely carry 260 kw. There should be an emergency feeder of the same size run from the store to the manhole at Fourth Street and Avenue B. for use in case of trouble on the regular feeder.

This completes all of the feeders for the entire distribution system and the next step is to design the 110-220 volt secondary lighting mains.

220-Volt Secondary Lighting Mains

The secondary mains for lighting are to be operated on a single phase, three-wire, 110-220-volt system and the load should be divided as evenly as possible between the three phases. There are many different arrangements of dividing the load and it is advisable to try several methods before deciding which is the most suitable.

In designing this system it is desirable to arrange the circuits

so that as few transformers as possible will be required, in order to save space in the vaults, save transformer investment, and to get the benefit of operating as large units as possible.

By arranging the mains so that only one phase is distributed from each vault the number of fuses, switches, junction boxes and other electrical equipment is reduced to a minimum. This not only reduces the cost but saves space which is frequently of vital importance in underground vaults.

The load in this district is fairly high and the blocks are about 350 ft. long, and as practically every building has to be supplied it is evident that by locating the transformers at street intersections they can supply the load in four directions.

Fig. 8 shows the 110-220-volt lighting mains and from which feeder they are supplied. Where mains extend from manhole to manhole they should terminate in junction boxes at each end, fusing the ends from which they are supplied and leaving the fuses out at the other end, to prevent crossing the phases. In case of trouble it is then possible to supply any main from either end by simply changing the direction of supply.

Referring to Table III in the summary of the lighting load it will be seen that the load is fairly well balanced on the feeders and that the load on each phase is nearly equal. This division of the load is, of course, based on the connected load and in the absence of actual data on the operating conditions is the only basis from which to work. After the system is in operation, or rather as the loads are being connected it is possible to alter these first plans so that a better balance can be obtained.

When installing an underground system it is advisable to make rules governing the size of load that is to be supplied by a two wire service. About 1300 watts is as large a load as should be supplied by a 110-volt two-wire service in a business district. All loads in excess of this should have three-wire services. It is advisable to install three service cables to all consumers as this will permit making changes easily when it is necessary to do so to balance the load.

The secondary mains for this system will be two single-conductor cables for the outers and a bare neutral, and the service cables will be three single-conductor cables.

The size of mains was calculated in the usual manner, and in practically every place where 200,000-cir. mil mains are shown on the plan, it will be found that No. 2/0 cable would carry the present load, but in a district such as this one it is not advisable to install any main of less than 200,000 cir. mils.

Where the mains on both sides of a street are supplied from the same phase and are tied together at the next manhole it is

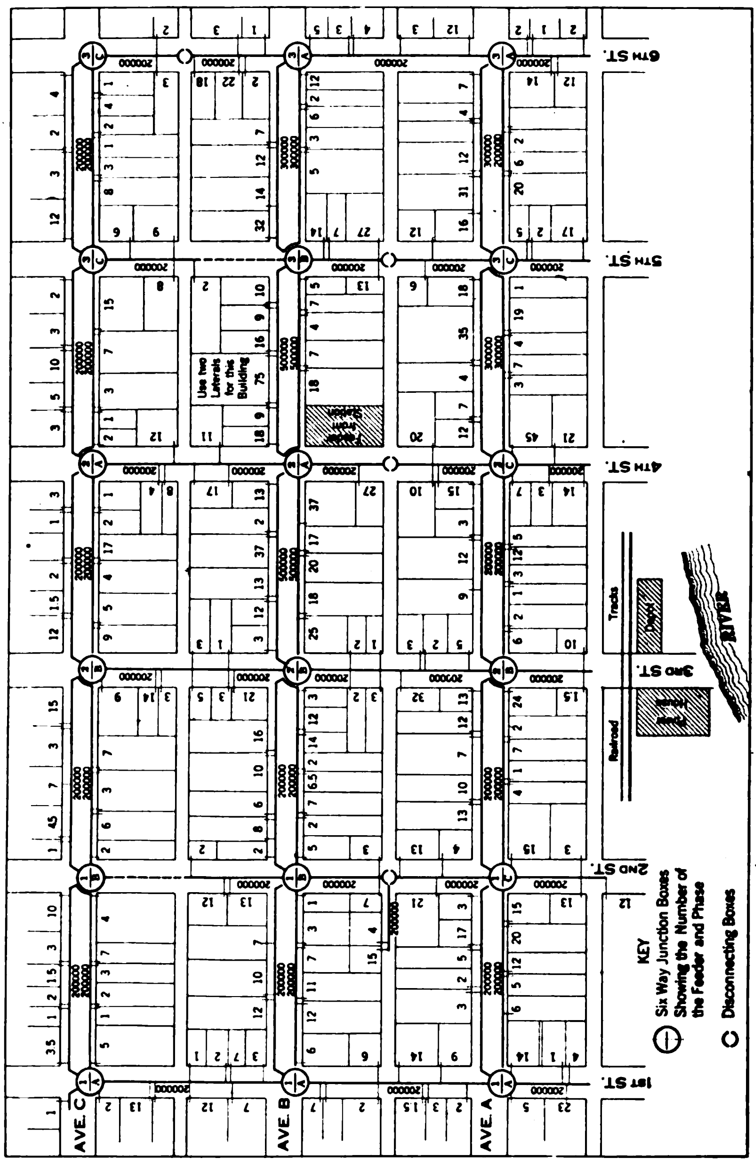

FIG. 8—220-VOLT SECONDARY MAINS

advisable to use the same size cable for both, regardless of the load on each, so that the main can be supplied from either end in case of necessity.

TABLE III—SUMMARY OF LIGHTING LOAD

Feeder No. 1 Block	Phase A	Phase B	Phase C	
No. 1	1.			
2	21.			
3		30.		
7	34.			
8	64.	25.		
9		62.		
13	15.5			
14	59.	66.	21.	
15		54.5	72.	
19	28.			
20	19.		83.	
21			56.	
	241.5	238.	232.	
Feeder No. 2				
No. 4		19.5		
9		55.		
10	67.	84.		
11	23.			
15		37.		
16	144.	37.	25.	
17			96.	
21		1.5		
22		10.	53.	
23			100.	
	234.	244.	274.	
Feeder No. 3				
No. 5			23.	
6			21.	
11		137.	38.	
12	107.		37.	
17		54.	6.	
18	28.	48.	82.	
23				
24	54.		24.	
6th St.	36.		2.	
	225.	239.	233.	

SUMMARY

Feeder	Phase A.	Phase B.	Phase C	Total
No. 1	241.5	238.	232.	711.5
No. 2	234.	244.	274.	752.
No. 3	225.	239.	233.	697.
	700.5	721.0	739.0	2160.0

The phases have been referred to as A, B and C and while this is the common practise a better method is to distinguish the

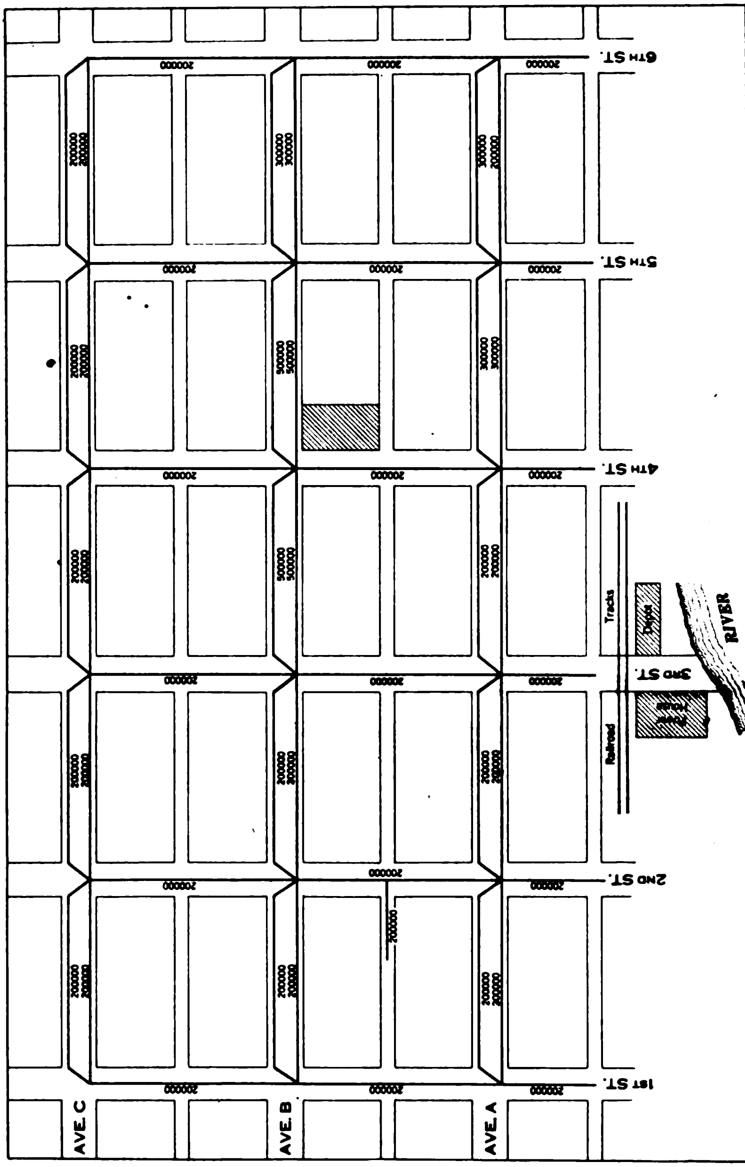

FIG. 9—BARE NEUTRAL MAINS

phases by colors, and paint the cables of each phase a different color, this method of marking the phases will prevent mistakes

in making connections as only cables of like color should be connected together.

The bare-neutral network is shown in Fig. 9 and is the same size as the outers wires shown in Fig. 8. Bare cable has been selected for the neutral in this system, but this is a matter that should be decided by the engineer for each particular system.

2200-Volt Secondary Lighting Feeders

The cables for this system can be either two- or three-conductor. While the lighting load is single-phase, still it is neces-

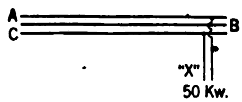

Fig. 10

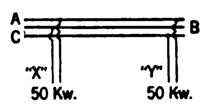

Fig. 11

sary to divide it between the three phases, therefore, the three-conductor cable has been selected so that all three phases are available at each transformer vault.

The following rules for calculating the temperature rise in three-phase feeders supplying one or more single-phase loads were devised by Mr. R. W. Atkinson and are given here with his permission.

Rule 1. A single phase load applied between two of the phases of a three-phase circuit (Fig. 10) is equivalent, insofar as the

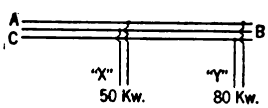

Fig. 12

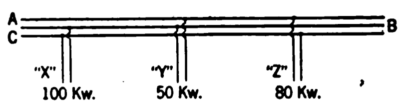

Fig. 13

maximum temperature rise is concerned, to a balanced three-phase load 50 per cent greater.

Rule 2. If two single phase loads, of equal magnitude, are applied, one between phases *A* and *B* and one between *A* and *C*, (Fig. 11) the maximum temperature rise is the same as for a balanced three-phase load 25 per cent greater.

Rule 3. If various single phase loads are applied between the various phases of a three-phase circuit (Fig. 12), the resulting load can be considered to be a combination of the two conditions just mentioned and a balanced three-phase load.

Referring to Fig. 13, and applying these rules the following result is obtained:

Phase	*A-B*	*B-C.*	*A-C.*		
Load....	50 kw.	100 kw.	80 kw.	= 230 kw.	
Subtract.	50 "	50 "	50 "	= 150 "	three-phase load at *X*
		50 "	30 "		
Subtract.		30 "	30 "	= 75 "	(60 × 1.25)
		20 "		= 30 "	(20 × 1.50)
				255 kw.	

Fig. 14 shows the secondary lighting feeders using three-conductor cable. The load, size of transformers and the phase from which they are supplied are marked at each feeding point.

Fig. 15 shows two-conductor single-phase feeders supplying this same system and the sizes shown on the plan are based on 70 per cent demand and as this system is used exclusively for lighting the power factor has been taken at 100 per cent. It will be seen that this system requires approximately 2000 ft. more conduit than the system shown in Fig. 14, and the approximate difference in cost of the two cable systems is as follows:

No. 6 three-conductor cable	4800 ft.	at $160.00...	$ 768.00
No. 2 " "	1200 "	" 340.00...	408.00
			$1176.00
No. 6 two-conductor cable	7200 ft.	at $100.00...	$ 720.00
No. 2 " "	800 "	" 204.00...	163.00
			$ 883.00

This is a difference of $293.00 in favor of the two-conductor cables on the cable alone, but if the additional conduit is considered it will be seen that the three-conductor cable is not only the cheapest but the better system to install.

There is another point to be considered in selecting the three-conductor cable; the sections will be in comparatively long lengths and if replaced by larger cable at any time the old cable can be

used in other places, even on the power system, while if two-conductor cable were used it would be available only for the

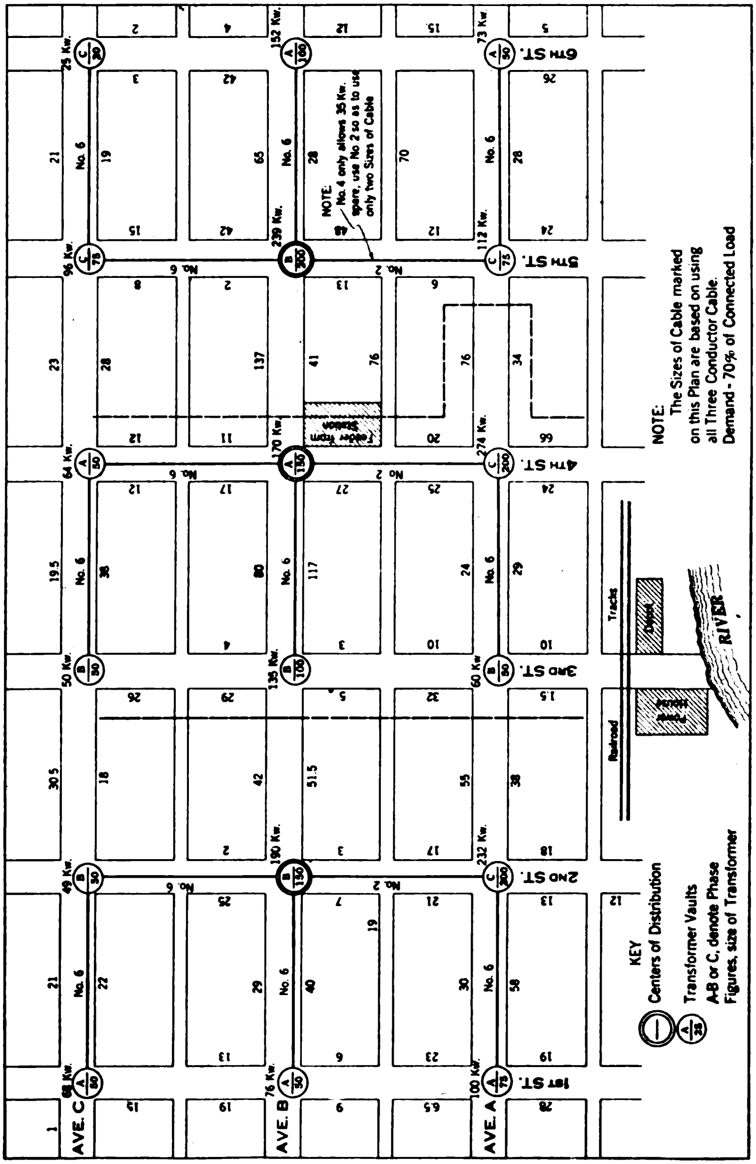

Fig. 14—Secondary Lighting Feeders

lighting system and would be an additional type of cable to keep on hand.

As the three-conductor cable will require less conduit, and be available for use on either system it is advisable to select it for

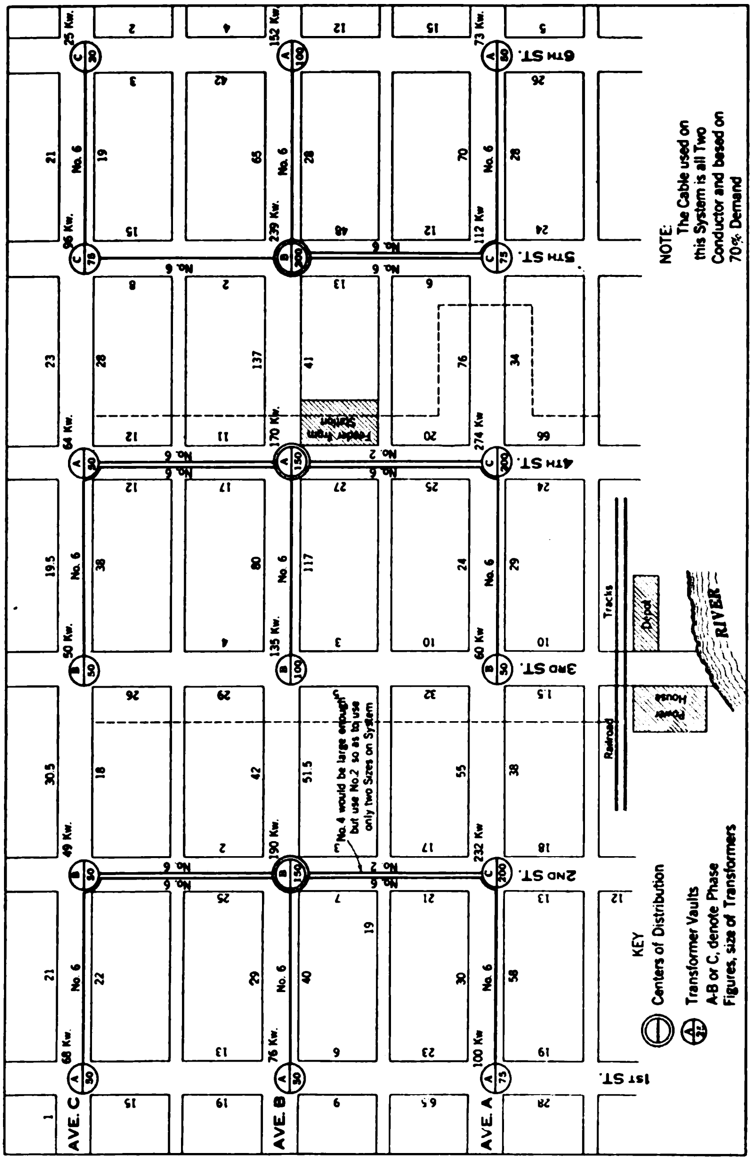

Fig. 15—Secondary Lighting Feeders

these feeders, as the system will be more flexible than if two-conductor cable were used.

The size of transformers is shown at each feeding point and is based on 70 per cent demand factor as follows:

SUMMARY.

Feeder	Connected load	70 per cent demand	Transformer capacity
No. 1	715 kw.	500 kw.	575 kw.
" 2	753 "	527	600 "
" 3	697 "	488 "	520 "
	2165 "	1515 "	1695 "

The total connected load is 2165 kw. and the transformer capacity is 1695 kw., or 78 per cent. This is not an excessive amount for a commercial district and it is doubtful if a much better arrangement could be made under the conditions assumed in these plans.

It must be remembered that plans, such as these, are made a long time before the work is actually done and are simply for estimating the cost of the system and are subject to final revision when the system is being installed. Owing to the fact that usually the grouping of the consumers on the new underground system will be entirely different from what they were on the overhead system, the demand factor can only be estimated, and as the new system is "cut over" gradually there is ample opportunity to select the size of transformers, balance the loads and get satisfactory results.

CONDUIT SYSTEM

The first thing necessary in designing a conduit system is to determine the number of ducts to be installed on each street and this can best be done by making a tabulation as shown in Table IV this will show definitely the actual number of ducts required and the proper number of spare ducts can then be added.

The system under consideration is for distribution purposes only and will consist of trunk ducts on the bottom, running from manhole to manhole, and distribution ducts on the top which pass through all of the intermediate handholes or service boxes.

The feeders will all be placed in the lower ducts and the secondary mains for the lighting and power system, and the street light cable will be in the distribution ducts.

Provision must be made for the following cables in the distribution ducts.

1 Three-conductor power main.

2 Single-conductor lighting mains (Outers).

1 Bare neutral for lighting system.

1 Street light cable (Two in some places, but they will be in one duct).

If separate ducts were used for each cable it would require 5 ducts on the top tier, this is a bad arrangement because it would increase the cost of the system, as the width of the trench would be about 29 in. using 3.5 in. conduit. The best arrangement would be to place one of the lighting mains and the neutral in one duct and install the conduit four ducts wide, which would require a trench about 24 in. wide.

By using four ducts for distribution it is possible to lay all of the conduit in multiples of four which is a very good arrangement. On streets having conduit on both sides it is only necessary to lay four ducts on one side, for distribution, keeping the main conduit on the other side of the street.

In systems where only three ducts are required for distribution it is sometimes advisable to use multiples of three in laying the conduit and thus make considerable saving in first cost. On all distribution systems the number of ducts wide should be determined by the number of ducts required for the distribution cables.

In laying four ducts they should, if the conditions will permit, be laid two wide and two high, in fact on all conduit systems, except for high-tension cables, it is advisable to have the conduit form as near a square section as possible as this makes a stronger structure. As far as the subsurface conditions will permit it is advisable to use a multiple of the distribution ducts as the number to install in one trench.

The conduit plan must show the point at which all laterals enter the buildings and the location of the street lights so that the service boxes can be located to the best advantage, the exact location, of course, depending on the subsurface conditions.

Fig. 16 shows the conduit arrangement for this system of distribution and is based on the tabulation shown in Table No. IV. To avoid confusion there is only one lateral shown entering each building but there should be two wherever power is to be supplied.

The size and location of the service boxes should be determined by the number of mains passing through them, the number of services that it is permissible to splice on a main at one service box, and the available space for locating them. Long laterals are expensive and require larger service cables, and it should be

remembered that to make a neat splice not more than two three-conductor services can be taken from a main in one splice.

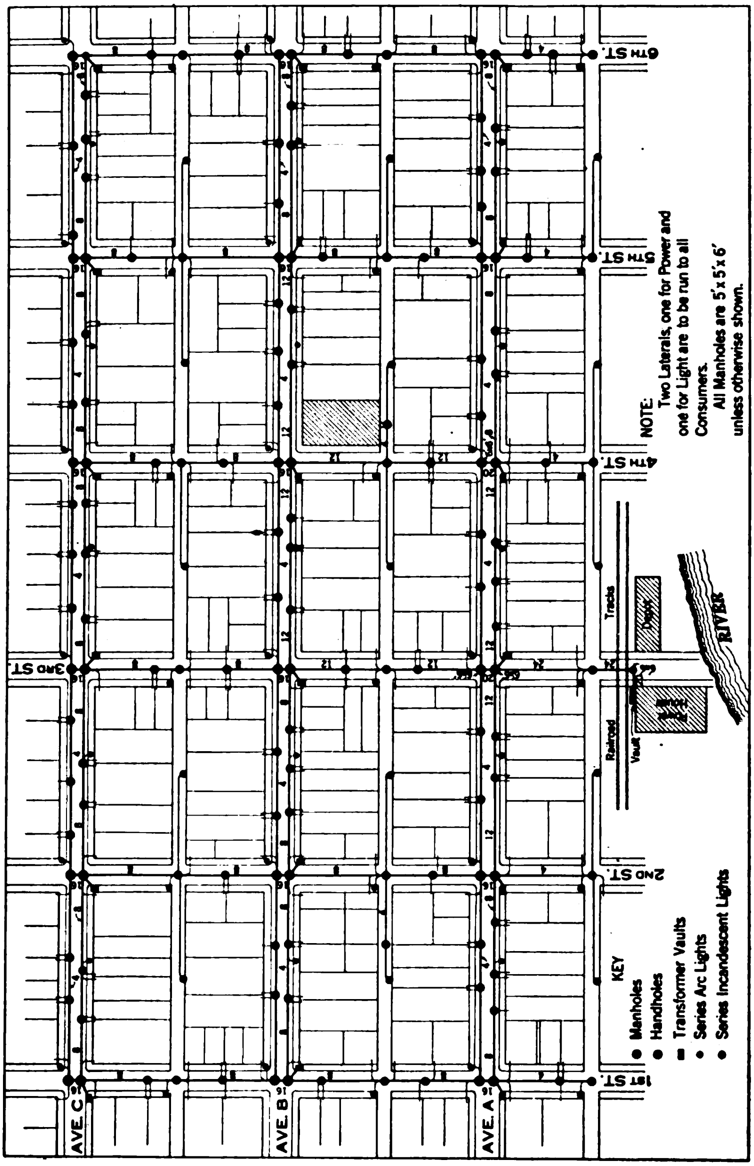

FIG. 16—CONDUIT SYSTEM

Where the mains are single conductor it is possible to take out four service cable from one splice.

On a system such as is considered here the service boxes should

TABLE IV.—SUMMARY OF CONDUIT

Side of Street	Street	From	To	Primary Power Feeder	Secondary Power Feeder	Primary Light Feeder	Secondary Light Feeder	Emergency Feeder	Private Feeder	Distribution	Spare Ducts	Total Duct
	First St.	Alley No.1	Ave. A.	....	....	....	....	....	....	4	....	4
	" "	Ave. A.	" B.	....	1	....	....	....	....	4	3	8
	" "	" B.	" C.	....	1	....	....	....	....	4	3	8
	Second St.	Alley No.1	" A.	....	....	....	....	....	....	4	....	4
	" "	Ave. A.	" B.	1	....	1	1	....	....	4	1	8
	" "	" B.	" C.	....	....	....	1	....	....	4	3	8
	Third St.	Station	" A.	2	....	3	....	1	1	4	13	24
	" "	Ave. A.	" B.	....	1	1	....	1	....	4	5	12
	" "	" B.	" C.	....	1	....	....	....	....	4	3	8
	Fourth St.	Alley No.1	" A.	....	....	....	....	....	....	4	....	4
	" "	Ave. A.	" B.	1	1	....	1	..	1	4	4	12
	" "	" B.	" C.	....	1	....	....	....	....	4	3	8
	Fifth St.	Alley No.1	" A.	....	....	....	....	....	....	4	....	4
	" "	Ave. A.	" B.	....	....	1	1	....	....	4	2	8
	" "	" B.	" C.	....	1	....	1	....	....	4	2	8
	Sixth St.	Alley No.1	" A.	....	....	....	....	....	....	4	....	4
	" "	Ave. A.	" B.	....	....	....	....	....	....	4	4	8
	" "	" B.	" C.	....	....	....	....	....	....	4	4	8
S	Ave. A.	First St.	Second St.	....	....	....	1	....	....	4	3	8
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	2nd St.	3rd St.	1	....	1	....	....	....	4	6	12
N	" A	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	3rd "	4th "	1	....	1	1	....	1	4	4	12
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	4th "	5th "	....	1	1	....	....	....	4	2	8
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	5th "	6th "	....	....	....	1	....	....	4	3	8
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	Ave. B.	1st St.	2nd St.	....	1	....	1	....	....	4	2	8
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	2nd "	3rd "	....	1	....	....	1	....	4	2	8
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	3rd "	4th "	....	....	1	1	1	....	4	5	12
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	4th "	5th "	....	1	....	....	1	....	4	6	12
N	" "	" "	" "	....	....	....	....	....	....	4	..	4
S	" "	5th "	6th "	....	1	....	1	....	....	4	2	8
S	Ave. C.	1st St.	2nd St.	....	....	....	1	....	....	4	3	8
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	2nd "	3rd St.	....	....	....	....	....	....	4	4	8
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	3rd "	4th "	....	....	....	1	....	....	4	3	8
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	4th "	5th "	....	....	....	....	....	....	4	4	8
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
S	" "	5th "	6th "	....	....	....	1	....	....	4	3	8
N	" "	" "	" "	....	....	....	....	....	....	4	....	4
	Alley No. 2	1st "	2nd "	....	....	....	....	....	....	4	....	4
	Alley No. 2	4th "	Big Store	....	....	....	....	....	....	4	....	4
	Station	To Manhole No. 1.		2	....	3	....	1	1	....	13	20

be about 3 ft. by 4 ft. and the depth will depend on the grade of the conduit, as the top tier of ducts must enter the service box. For the purpose of estimating, it may be stated that on a system of this kind that the average depth of service boxes will be from 36 to 40 inches.

Where subway junction boxes and other electrical equipment must be placed in manholes, this fact must be taken into consideration in determining the size of the manholes, but in a system

TABLE V—SIZE OF CABLE FOR LATERALS. INDIVIDUAL CONSUMERS LOADS

Load	Number of Consumers	Size of Cable
For Power		
0 to 10 kw.	92	3 Conductor No. 6
11 " 20 "	29	" " " 4
21 " 40 "	8	" " " 1/0
	129	
For Lighting		
0 to 10 kw.	168	3 Single Conductor No. 6
11 " 15 "	48	" " " " 4
16 " 35 "	30	" " " " 1/0
36 " 65 "	4	" " " " 4/0
	250	

Assume that laterals will average 60′ long each and that three-conductor cable is used for all power laterals and three single-conductor cables for the lighting consumers, therefore each lighting lateral will require 180′ of cable.

where transformer vaults are built the manholes need only be large enough to permit training the cables properly.

Where electrical equipment is to be installed in manholes it is advisable to build them with square corners as this space is frequently very desirable.

If possible, transformer vaults should be located under the sidewalk (Fig. 17) and on the same side of the street as the main conduit. By locating the vaults under the sidewalk there is less liability of damage from being flooded, also they can be more easily entered in the winter when the ground is covered with ice

and snow. All covers to manholes, or vaults, under the sidewalk should be filled with cement to match the color of the walk and also prevent pedestrians from slipping on them.

In many of the old systems, where a large number of ducts were laid in one trench, the manholes were entirely too small to permit the cables being properly trained in them. In a small system, such as this one, large manholes are not required, as it is proposed to locate the transformers in vaults and have only the cables and secondary junction boxes in the manholes.

By locating the transformers and the 2300-volt equipment in the vaults and the low tension junction boxes in the manholes there is less liability of a burnout damaging the secondary net-

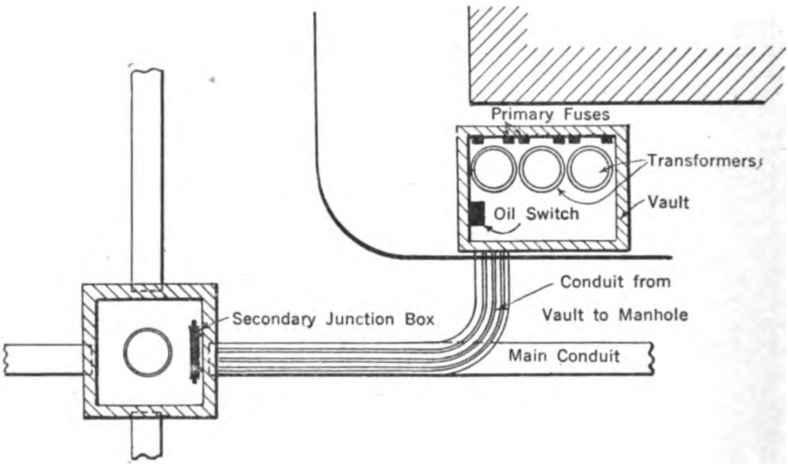

FIG. 17

work, also the mains are shorter, and less conduit is required between the vaults and manholes.

Fig. 18 shows a typical arrangement of conduit and manholes at a street intersection, each duct between manhole *A* and *B* is numbered to correspond with the ducts leaving manhole *B*.

Owing to the obstructions usually encountered at street intersections, it is generally necessary to build two manholes, but where the grade of the conduit can be maintained across the street it is only necessary to have a service box on one side, deep enough to take the two top tiers of ducts.

If the secondary junction boxes are installed in the vaults it will be necessary to have 18 ducts between the manholes and vaults as follows:

1 Power feeder.
1 Lighting feeder.
1 Emergency feeder.
6 Power mains.
6 Lighting mains.
1 Ornamental street light (may be required).
2 Spare ducts.

While it will not require six ducts each for power and lighting mains in all cases at present, still provision should be made for this number eventually.

In making the estimate for this system the following figures will be taken as being fairly accurate.

All service laterals will consist of two ducts and will average

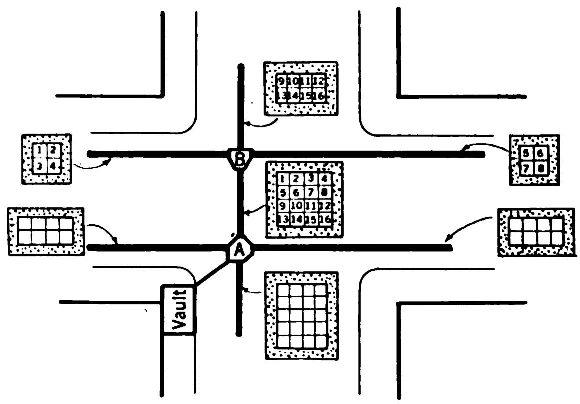

FIG. 18—ARRANGEMENT OF CONDUIT AND MANHOLES AT STREET INTERSECTION

20 ft. long from the trench to the property line, on streets where there are two lines of conduit, and 30 ft. long on streets having but one line of conduit.

Street light laterals 10 ft. from trench to lamp pole, the lights in the alleys having a single fibre-duct lateral 180 ft. long.

Street crossings and the distance from manholes to vaults are 30 ft. each.

A vault is shown at the station and is frequently required in large systems, but in a system of this size it is very probable that the conduit could enter the basement of the station at the most convenient point for the various systems.

The size of the transformer vaults will depend on the amount of equipment that is to be installed in them. For this estimate

it will be assumed that the three vaults at the centers of distribution are 10 by 15 by 8 ft. and all other vaults 10 by 12 by 8 ft. As this district is to be extended later and will probably require larger transformers when the load increases, it is advisable to make the manholes as small as possible and allow sufficient room in the vaults to permit installing the equipment in a neat and workmanlike manner and have sufficient room for operating it safely.

The transformer capacity that can be installed in a vault without providing special ventilating facilities will depend on the operating conditions. For transformer capacities not exceeding 200 kw., under favorable conditions, 3.5 to 4.0 cubic feet of vault space per kw. will permit safe operation; these figures correspond fairly well with the rule for allowing 8 watts transformer losses per square foot of radiating surface in the vault, figuring the sides and ceiling as follows:

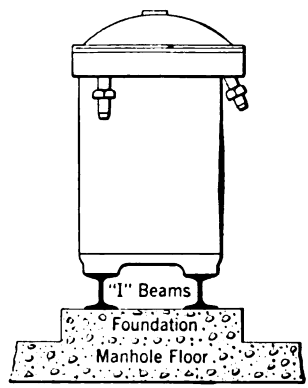

FIG. 19

Assume four 50-kw. transformers installed in a vault 10 ft. by 10 ft. and 7 ft. high. A 50-kw. subway transformer has 240 watts core loss and 550 watts copper loss, or a total of 790 watts and four such transformers will have 3160 watts loss. A vault 10 by 10 by 7 ft. contains 700 cubic feet and has 380 square feet of radiating surface, counting the walls and ceiling.

Allowing 3.5 cubic feet per kw. this would give exactly 700 cubic feet required, which is the size of the assumed vault. Applying the rule of 8 watts loss per ft. of radiating surface the result is 8 × 380 or 3040 watts, which corresponds very closely with the first estimate.

•The above losses are based on the assumption that the transformers are fully loaded but in a large distirbution system where the transformers serve both lighting and power loads this is seldom the case as the maximum lighting and power loads rarely occur at the same time, and the overlap of these demands is usually of such short duration that no serious rise in temperature results from this cause.

The above method can be used to calculate the size of vaults for a given transformer capacity not exceeding 200 kw., still it is

always necessary to allow sufficient space to properly install and operate the equipment in the vault.

In installing transformers in vaults it is advisable to have them raised above the floor, and if possible mounted on two or three I beams as this permits the air to circulate all around them. (See Fig. 19.) It is a good plan to have a thermometer in each vault and keep a record of the temperature as a guide to the actual conditions. Where this is done the thermometer should be noted immediately on entering the vault before the air has a chance to cool; in taking the temperature of the transformers the thermometer should be placed at the oil level of the transformers.

Having determined the general arrangement of the conduit system the next step is to select the most suitable location in the streets for installing it. In order to plot the location of sewers, pipes and other obstructions it is necessary to prepare a map of each street and alley on a scale of about 20 ft. to the inch.

Records of subsurface conditions are usually far from accurate, but by getting the location of all gates, covers, etc. visible on the surface of the streets it is frequently possible to prepare a very fair plan of the actual conditions. All existing manholes should be entered and measured and they should be laid out accurately on the plan, allowing for the thickness of the walls, as getting the new conduit by existing manholes is frequently one of the most difficult points in conduit construction.

It is a good plan to make two sets of these large scale street maps, one showing the obstructions and the other one to show the new system exactly as it is installed for future reference. These latter drawings should be made on cloth backed drawing paper and can be kept in rolls, and all additions and changes should be entered on them when made, giving the date and all details of the work.

Manholes are built of brick or concrete, except in special cases there is little difference in the cost. In streets where the space is limited and many obstructions are encountered it is cheaper to build brick manholes, but in residential sections, or for high tension systems, it is frequently cheaper to build concrete manholes when a standard form can be used.

In locating and building manholes every effort should be made to avoid any pipes passing through them, it is frequently possible to change pipes or cut them around the manhole and this should be done if permitted.

The service boxes should be built of brick as owing to their difference in depth a standard form can not be used to advantage.

Vaults, where built under the sidewalk, should be of concrete and have suitable ventilating pipes extending up the side of buildings or adjacent poles. There should be one pipe located

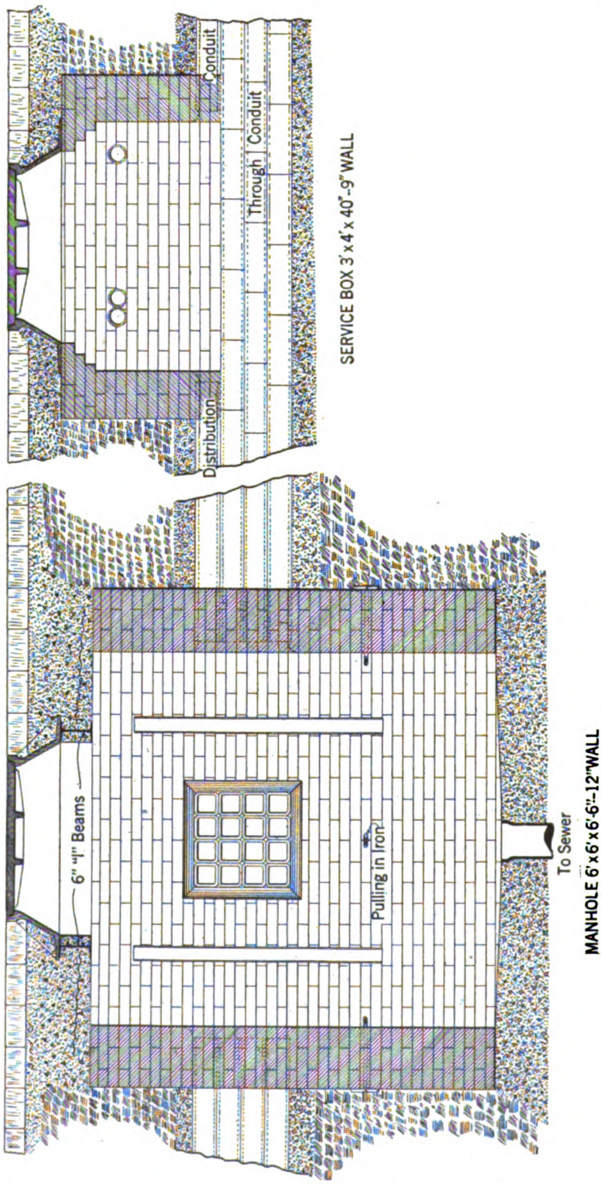

Fig. 20—Manhole and Handhole

low at one end of the vault and one located high at the other end and care should be taken not to locate transformers directly under the ventilating pipes.

Fig. 20 shows the usual arrangement of manholes and vaults. Owing to the increase in weight of automobile trucks it is very important that all casting be made much heavier than was done formerly. The castings should be inspected at the foundry, or before being placed, to see that the covers set firm and solid in the seat of the casting. No loose or uneven covers should be permitted for no amount of chipping or grinding will make them satisfactory.

Single cover castings are advisable and they should have ventilating holes in the covers for the manholes but the service box

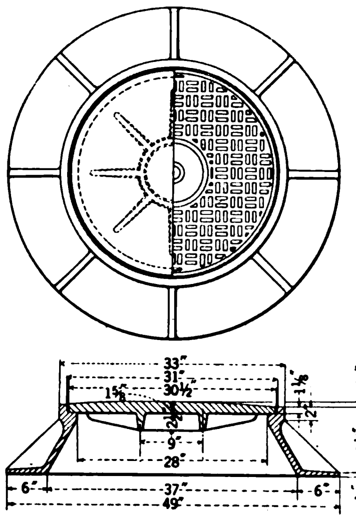

FIG. 21—MANHOLE CASTING

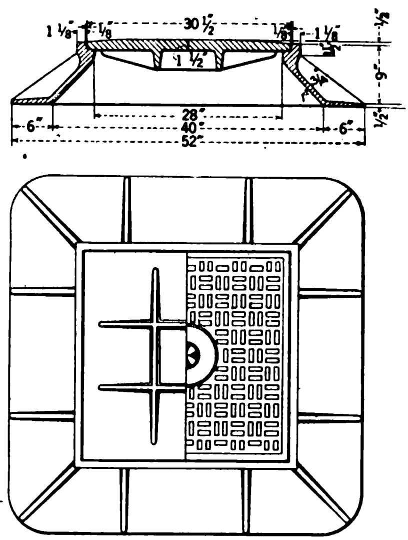

FIG. 22—HANDHOLE CASTING

castings should be unventilated, Fig. 21 and 22 show castings for manhole and service box respectively.

If possible, it is advisable to locate the conduit about five feet from the curb so as to keep the service box covers out of the gutter and if possible locate the conduit outside of the gas and water main as it will not then be necessary to sandwich the conduit around the service pipes for those systems.

All vaults and manholes having electrical equipment in them should be connected with the sewer and the floors should be sloped in all directions to the sewer outlet.

Cable racks should not be placed until the cable is being installed, except on high-tension systems where the arrangement of the cables will be uniform in all manholes.

When building vaults, or manholes where transformers are to be installed, it is advisable to install a suitable ground connection at the time of construction, a ground cone, or one-in. galvanized pipe should be used if it is not possible to connect to the water pipe system, but whatever kind of ground is decided on care must be taken to make it permanent and reliable, for large vaults it is advisable to install two ground connections.

The conduit as laid out in Fig. 16 is the usual method adopted in systems of this kind. There is, however, another method that can be adopted in some cases which will permit a very material saving in conduit and should be given serious consideration where the geographical arrangement of the city permits.

Take this same district, and referring to Fig. 16, install twelve ducts on each side of 3rd Street from the station to Avenue A., and make the main conduit line east and west on Avenue A.,

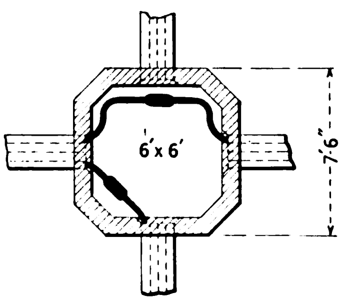

FIG. 23—ORDINARY ARRANGEMENT OF MANHOLE

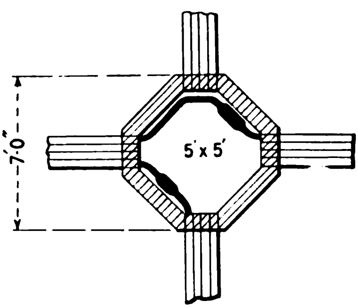

FIG. 24—PROPOSED ARRANGEMENT OF MANHOLE

and run all feeders over this route branching them off at the north and south streets, as 1st, 2nd, etc., this would permit reaching every distribution point.

On such streets as Avenue B. and C. it would only be necessary to install four ducts on each side of the street for distribution this would make a saving of approximately 17,000 ft. of conduit on those streets but it would be advisable to add more conduit on Avenue A.

Possibly a modification of this plan would be better, that is, to make the main conduit lines on Avenue A. and on 3rd Street, the saving would probably be about 10,000 ft. If later a substation were to be installed to feed other sections of the city this plan would be very desirable as it is only necessary to have ducts on the avenues sufficient to provide space for the distribution cables and street light system.

Subway Junction Boxes

When the load in a district is supplied by a low-tension network it is necessary to supply facilities for fusing and disconnecting the mains. When the low-tension network is supplied by low tension alternating- or direct-current feeders this is a simple matter but where a low-tension network is supplied by subway transformers the conditions are more complicated and additional equipment is necessary to insure reliable service, as both the primary and secondary systems must have protective, sectionalizing and switching facilities. Where the power and lighting load are supplied separately this practically doubles the equip-

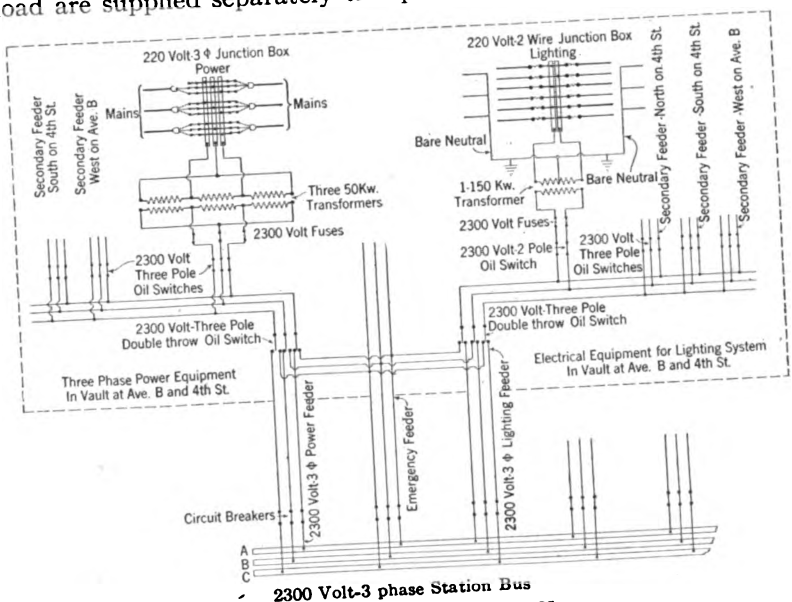

Fig. 25—Diagram of Equipment in Vault

ment and space required, and greatly increases the cost of the system.

Fig. 25 shows the method of protecting, sectionalizing and switching used on the lighting and power systems; it is a diagram of what would be necessary in one of the vaults, the one chosen for illustration being the vault at Avenue B. and Fourth Street.

It will be seen in case of trouble on one of the regular lighting or power feeders that the load can be switched over to the emergency feeder. Should one of the secondary feeders fail it would cut off the supply to all of the transformers connected to it, but by disconnecting these transformers from the network and con-

necting this portion of the network to other phases (by putting the fuses in at the several junction boxes) the system could be operated temporarily even though greatly unbalanced.

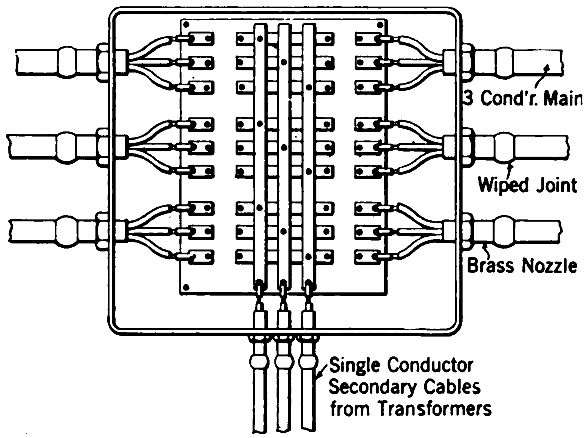

FIG. 26—THREE-PHASE JUNCTION BOX—FOR POWER

If greater security were desired it would be necessary to install "tie feeders" as shown by the dotted line on Second Street, in Fig. 6.

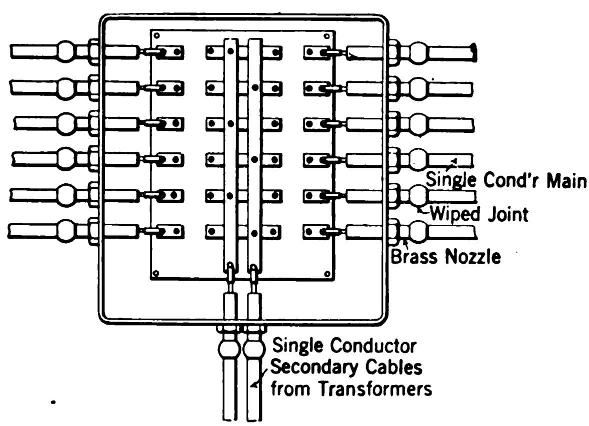

FIG. 27—TWO-WIRE—220-VOLT JUNCTION BOX—FOR LIGHTING

The mains are protected by fuses at each end and in case of trouble on them, or the house services, would be cut off automatically; where there are mains on both sides of the street the

number of consumers affected in case of trouble is considerably reduced. The fuses on the mains should be heavy enough to carry at least 50 per cent more current than the normal carrying capacity of the mains, as it is not desirable to have the fuses blow out except in case of serious trouble.

It will be noticed that in Fig. 25 only three fuses are shown on the primary side of the power transformers. In actual practise, where fuses are used on the primary side, it is better to install two fuses for each transformer. There is considerable difference of opinion among engineers as to the advisability of installing any fuses on the primary side of subway transformers as they generally cause more trouble than their protection is worth, but as it is advisable to have some point where the transformers can be easily disconnected from the feeders it is a good plan to install the fuse boxes and use fuses having 100 per cent greater carrying capacity than is required to protect the transformer and then trust to the station circuit breaker to disconnect the feeder in case of serious trouble.

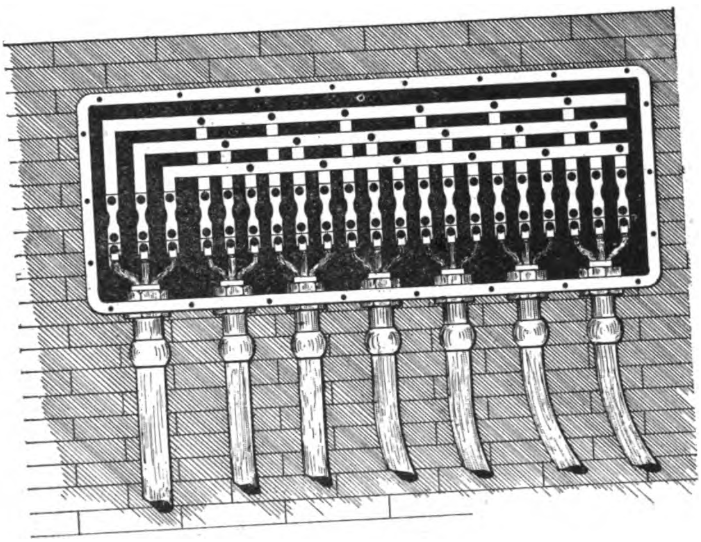

FIG. 28

Assuming that the system is to be installed as shown in Fig. 25, the subway junction boxes shown would provide facilities for disconnecting and fusing the various mains. The junction boxes for the lighting system would be fitted for single conductor cable and those for the power system for three conductor cable.

Owing to the fact that there are so many different systems in use there is no standard type of junction box that can be specified, and it is generally necessary to design boxes for each system to meet the conditions. In underground work there is probably no part of the system that is more liable to cause trouble than are the junction boxes; this is not always due to defects in the box but to careless work in installing it or not properly closing the cover.

Fig. 28 shows a type of junction box that is well suited for subway installation, it is placed near the top of the manhole and the cables all enter it from the bottom, it is practically certain that a box of this type will never get flooded as the water would not rise above the conduit unless the entire system got flooded which is very unlikely.

When the fuses on a transformer blow, its load is transferred to the adjacent transformers and they become overloaded and their fuses blow. This is a serious matter as this condition usually occurs at the most inconvenient time, and where additional security is warranted it is advisable to install the "alternating-current network protector."

Having completed the designs for all of the various systems it is only necessary to scale off the amount of material from the plans and tabulate the equipment, as specified in the text or from the plans. Space will not permit giving these various estimates completely but the following samples will show the method to be adopted.

Conduit System

Conduit in main trench	139,500 ft.
Trench feet	17,145 "
Conduit for laterals in main trench	4,110 "
Conduit for laterals run separate	10,650 "
All conduit used for laterals to be 3-in. fibre.	
Manholes	37 "
Handholes	108 "
Vaults 10 by 12 by 7 ft	15 "
Vaults 10 by 15 by 7 ft	3 "
Sewer Connections	18 "

Three-Phase Power System

2300-volt	three-condr.	Cable	No.	2/0	3,700 ft.	primary feeders		
2300-	"	"	"	"	4	1,100 "	"	"
2300-	"	"	"	"	6	2,600 "	"	"
220-	"	"	"	"	1/0	4,600 "	secondary mains	
220-	"	"	"	"	4	12,700 "	"	"

220- " " " " " 6	5,520 "	laterals
220- " " " " " 4	1,740 "	"
220- " " " " " 1/0	480 "	"
25-kw. transformers	16	
50- " "	9	
2300-volt subway fuse boxes	50	
3-pole single throw oil switches	6	
3-pole double throw oil switches	3	
6-way junction boxes	18	
0 30-ampere consumers fuse boxes	70	
31 60- " " " "	23	
61 100- " " " "	27	
101 200- " " " "	9	

The other systems should be handled in the same manner, after which the total cost can be calculated and the specifications prepared.

To be presented at the 338th meeting of the American Institute of Electrical Engineers, Cleveland, Ohio, March 8, 1918.

SELECTION OF STEEL MILL AUXILIARY MOTORS AND CONTROL AS AFFECTED BY MECHANICAL FEATURES OF THE DRIVE

BY J. D. WRIGHT

ABSTRACT OF PAPER

The author describes manipulators for blooming mills, which consist of side guards and lifting fingers, the former being used to guide the bloom into the proper groove in the rolls while the latter are used for turning the bloom over. The functions, mechanical layout and operation of these manipulators are described, from which conclusions are drawn as to the size and type of motors as well as the type of control best suited for driving these auxiliaries.

USUALLY the first questions which one is likely to ask when considering the proper type of motor and control for any steel mill auxiliary machine, are, "What is its function; what is the mechanical layout, and how does the device operate?" Without a thorough knowledge of the answers to these questions one is unable to make an intelligent recommendation on the application of either motors or control.

When discussing Standardization of motors and control at a meeting of the A. I. and S. E. E. in Pittsburgh about a year ago, Mr. Friedlander, of the Carnegie Steel Co. said, "What we need is more papers descriptive of installations and operation of our mills. In such a way we would gradually get uniform ideas about general requirements at all our mills and thereby drift toward a stable system of standardization." The PROCEEDINGS of the A. I. E. E. and A. I. and S. E. E. contain very few papers describing installations and operation of steel mill auxiliary apparatus and the writer heartily agrees with Mr. Friedlander's remarks regarding the need of such descriptive articles.

It is, therefore, the purpose of this paper briefly to describe a few steel mill auxiliary machines with particular reference to their mechanical details.

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Manipulators for Blooming Mills

Manipulators for blooming mills consist of side guards and lifting fingers. The function of the former is to guide the bloom into the proper groove in the rolls while the latter are used for turning the bloom over.

A reversing mill is usually provided with four moving side guards two on each side of the mill, one guard on the side of the mill with the operators pulpit being provided with the lifting

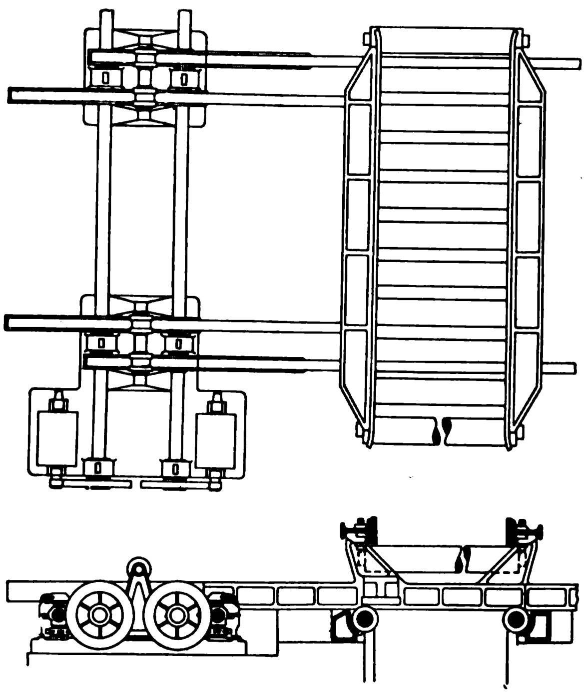


Fig. 2—Operating Mechanism for Manipulator Side Guards

fingers. Occasionally a set of lifting fingers is provided on each side of the mill, but as the bloom is usually turned only on the pulpit side, fingers are more commonly provided only on that side.

Fig. 1 is a general view of the entering side of a reversing blooming mill equipped with electrically operated manipulators. The two side guards are clearly shown and, on close inspection, the lifting fingers may be seen just inside the left hand guard.

Each side guard on the entering side of the mill is connected

by suitable mechanical means to the corresponding guard on the delivery side, so that the right hand and left hand guards on opposite sides of the mill always have the same movement and are always in line.

Fig. 2 shows one method of mechanical connection between the motors and the side guards. Two motors, one on each side of the mill, are geared through slip clutches to a common shaft on which are mounted four pinions which engage with four racks. Two of the racks are attached to one guard on the entering side and the other two to the corresponding guard on the delivery side of the mill.

The remaining two guards on opposite sides of the mill are similarly operated by a second pair of motors. The racks are supported by rollers and mechanical stops are provided to limit their outward movement.

Fig. 3 is a view of the same mill shown in Fig. 1 but gives a more detailed view of the side guard mechanism.

As previously stated, the function of the side guards is to guide the bloom into the proper groove in the rolls. The operation of the guards during the process of rolling an ingot consists, therefore, of many fast, short movements back and forth across the table. Each guard on one side of the mill can move independently of the other and can make a stroke equal to the width of the table. It is possible therefore for the guards when moving inward to come together or against the ingot at full speed. It is the function of the slip clutch to prevent damage as a result of such action should the operator be careless enough to allow it to occur.

The motor equipment for the side guards illustrated in Figs. 1 and 3 consists of four 80-h. p. series motors, two connected in series driving each pair of guards. Satisfactory operation of the guards requires rapid acceleration and retardation, and for such service series motors are most desirable. Some installations, however, use compound wound motors, primarily because dynamic braking for stopping was desired. Furthermore, solenoid brakes are sometimes used to assist the dynamic braking. In the equipment illustrated, neither dynamic braking nor solenoid brakes are used. When a quick stop is desired the motors are plugged. The equipment is therefore extremely simple.

The control for each pair of motors is of course reversible and is arranged so that a bank of resistance is permanently connected in series with the motor armatures. This acts as a buffer and

reduces the shock when the guards jam together or against the ingot. A one-point reversible master controller is used for each pair of motors. Limit switches are provided for cutting off power when the side guards are moved to the edge of the table. These limit switches are usually of the track type and are operated by movement of the rack. A geared switch might be used but the track type switch is much simpler and more positive in action.

The lifting fingers, which are used for turning the bloom over, are carried by a frame attached to the two inside racks connected to one of the side guards. They therefore move back and forth with the guard. See Fig. 4. The fingers are located just inside the guard and their lower ends are pinned to a yoke which

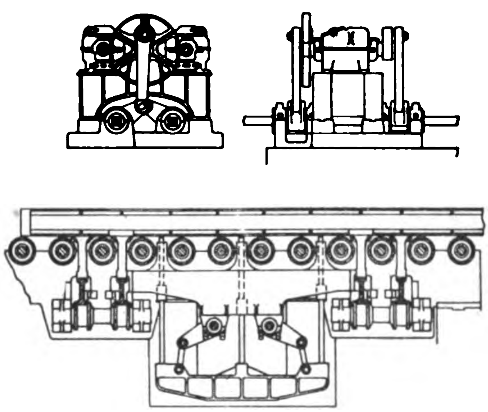
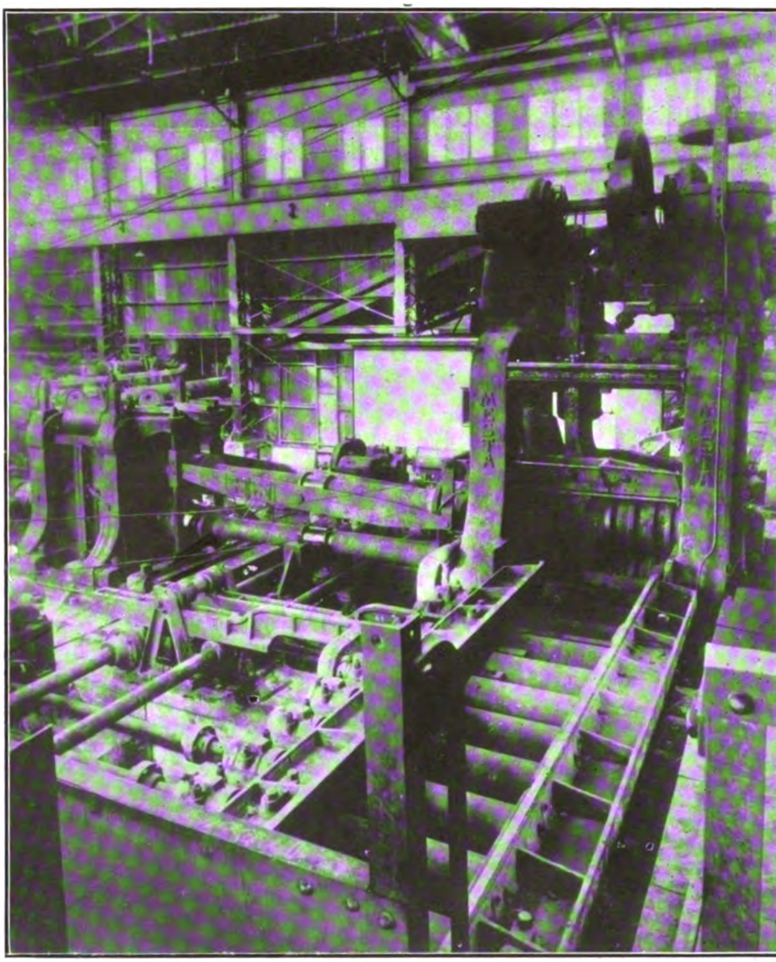


FIG. 4—OPERATING MECHANISM FOR MANIPULATOR FINGERS

is suspended from two horizontal shafts by means of two links and levers. The two horizontal shafts, which are supported by bearings in the finger frame, are connected through cranks to a common driving shaft. On this shaft is mounted a large gear to which the two driving motors are geared. It is evident that one-half revolution of the main driving shaft in either direction from the position shown in Fig. 4 will produce a complete up stroke of the lifting fingers. Another one-half revolution would produce a complete down stroke and return the fingers to their orig nal position.

The motors may therefore be either reversible or non-reversible. Successful installations of each have been made. When a non-reversing equipment is used, one complete cycle



[WRIGHT]

FIG. 1—BLOOMING MILL WITH ELECTRICALLY OPERATED MANIPULATORS

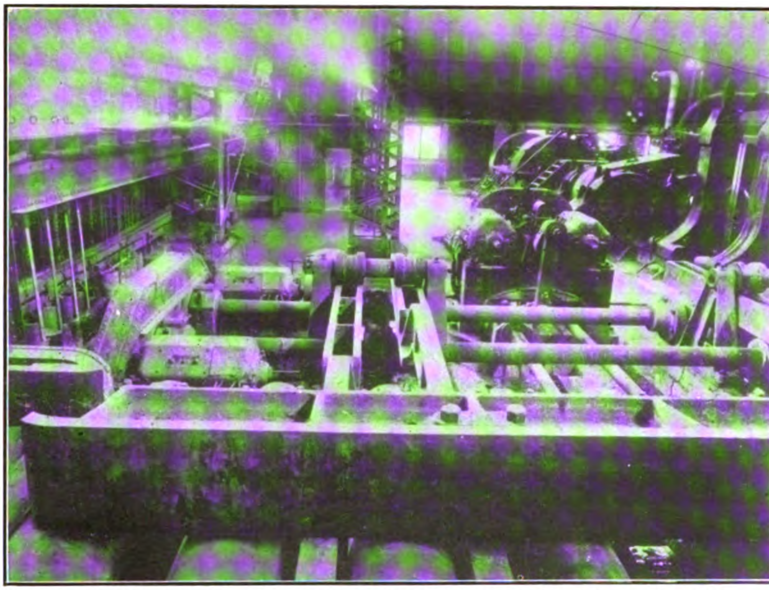
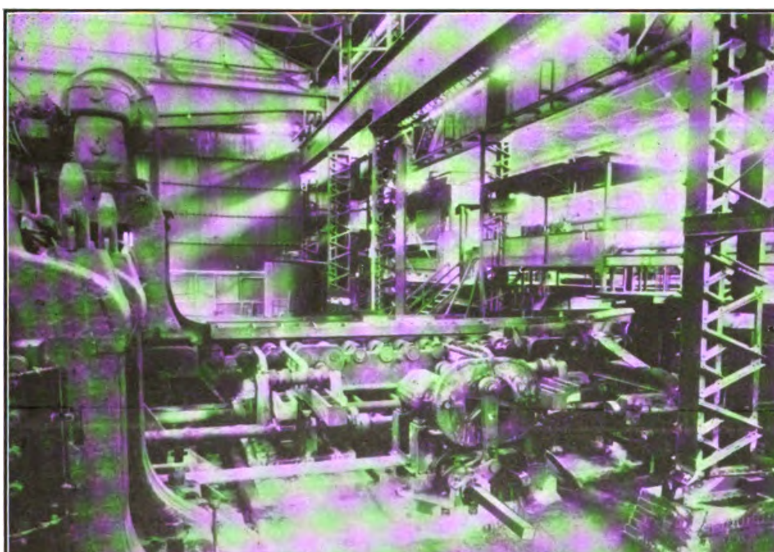


FIG. 3—GENERAL VIEW OF OPERATING MECHANISM FOR MANIPULATOR FINGERS AND SIDE GUARDS



[WRIGHT]

FIG. 5—VIEW OF BLOOMING MILL WITH ELECTRICALLY OPERATED MANIPULATOR FINGERS AND SIDE GUARDS

consists of an up and down stroke of the fingers. When a reversing equipment is used forward direction of rotation may produce the up stroke and reverse rotation the down stroke.

The motor equipment illustrated in Figs. 3 and 5 consists of two 50-h. p. series motors connected in series, operating non-reversing. For each throw of the operator's master controller a complete up and down stroke of the fingers is produced. The motors are automatically stopped at the end of the down stroke by a limit switch which cuts off power and completes a dynamic braking circuit.

The dynamic braking connections for a series motor operating non-reversing are comparatively simple. Where reversible control is used, a compound wound motor is preferable if dynamic braking is desired, as the control connections are simplified. Solenoid brakes are required if the equipment is reversible, whereas if non-reversible, no brakes are necessary. It has at times been stated that the operator should be able to control the stroke of the fingers. This of course necessitates the use of reversible control, but the movement of the fingers is so rapid that it very frequently happens that the fingers make a complete up stroke before the operator throws his master controller to the reverse position to lower them.

It has been shown that for the side guards shown diagrammatically in Fig. 2 a reversible equipment must always be provided. The motors may, however, be either series or compound wound. Dynamic braking and solenoid brakes may or may not be used. The operator's master controller may be one-point revers ble or multi-point reversible. Track type limit switches or geared limit switches to limit the movement of the side guards may be used.

For the lifting fingers in Fig. 4 it has been shown that the equipment may be either reversible or non-reversible. The motors may be either series or compound wound. Dynamic braking and solenoid brakes may or may not be used. The operators master controller may be one-point or multi-point reversible or non-reversible. The limit switch may be arranged to stop the motors when the fingers are at the end of their down stroke if the control is non-reversible, and if reversible the limit switch may be used to stop the motors with the fingers in both up and down positions.

There must, however, be one method of operating these devices which is superior to all others. What this method may be can

be determined only from actual operating experience, and it is to the steel mill electrical engineers that we must look for the results of such experience The writer sincerely hopes that Mr. Friedlander's suggestion may be followed and that we may have more papers on installations and operation of auxiliary drives.

To be presented at the 338th meeting of the American Institute of Electrical Engineers, Cleveland, Ohio, March 8, 1918.

SOME CONSIDERATIONS IN DETERMINING THE CAPACITY OF ROLLING-MILL MOTORS

BY ROBERT F. HAMILTON

ABSTRACT OF PAPER

A consideration in detail of electric drive for rolling mills, including classification of mills and motors, mathematical determinations of energy required for rolling, relation of speed to tonnage, motor capacity and flywheel application.

FOR several years past the attention of engineers in Great Britain has been directed to the electric driving of rolling mills. This is a natural result of the constantly increasing use of electric power for auxiliary apparatus in steel works, and the economies which accompany generation of power in large units. When blast furnace gas may be utilized under boilers for turbo-generators or for driving gas engine units the prospects of electric motor application throughout an entire works are very favorable. The present demand for steel has accelerated the application in that it has caused many manufacturers to scrap existing plant and adopt more modern methods. In a very few months the steel production of the nation has changed from what might have been called a decaying industry into a vital necessity.

GENERAL CLASSIFICATION

In any rolling-mill electrification the paramount problem is the delivery of a specified tonnage of steel, of which the grade and section are known, at a minimum total cost. Each case must therefore be analyzed carefully and the most suitable equipment chosen. In general, the drives may be classified as follows:

1. Continuous running mills.
   a. Constant-speed motors.
   b. Adjustable-speed motors.
2. Reversing Mills.

Item 1 may include two-high or three-high mills, of nearly all types, *i. e.*, plate mills, sheet mills, cogging or blooming mills,

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merchant mills, rod mills, etc. By far the greater number is driven by constant-speed motors. Adjustable-speed motors are found where it is desirable to roll a variety of sections in the same mill.

One of the most efficient drives is by means of a high-speed induction motor with ropes or gearing. If speed variation is necessary this may be accomplished in the case of an induction motor by controlling the rotor frequency with a synchronous converter or alternating-current commutating-motor. Instead of the adjustable-speed induction motor it is often found advisable to use adjustable-speed direct-current motors and synchronous converters, assuming of course, that the supply is an alternating-current system. If the first mentioned scheme includes an auxiliary motor on the shaft of the main motor, constant power output may be obtained at the rolls throughout the range of speed. When it is necessary to increase the speed of rolling, the torque required is usually less, which condition is also met by a direct-current motor with shunt-field control. In a few special cases cascade motors or Ward-Leonard motors have been used to drive continuous mills.

The reversing mill is best suited to the work of cogging ingots to billets. The speed of rolling is changed from pass to pass as the billet lengthens and the reversing does away with the lifting tables, which are generally necessary in a three-high mill. Electric motors which are to meet such service must be capable of withstanding large overloads, since no flywheel is interposed between the motor and mill. Ward-Leonard control is used over the range of speed in which the torque is a maximum, and shunt-field control at the top speeds when the torque is reduced. An Ilgner set supplies the energy for the motor.

Selection of Mill

The type of mill is determined by the tonnage and sections rolled; the temperature at which the rolling takes place; the quality and composition of the product; the general layout of the steel works and the labor conditions existing in the particular district. The latter is emphasized in the consideration of automatic features and skilled attendance.

This discussion presumes that the following facts have been determined:

1. Type of mill including layout.
2. Weight, shape, material and temperature of ingot or billet.

3. Section and tonnage of finished product.
4. Diameter and profile of the rolls.
5. Time required to handle material between passes.

Energy Required for Rolling

Opinions vary as to the methods employed in calculating the energy required for rolling. Many engineers use a formula which includes the logarithm of the elongation. That is, the torque in any pass is proportional to the logarithm of the elongation of the

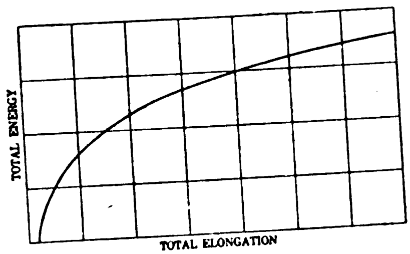

Fig. 1

material during the pass. A basis for this method may be found by plotting a curve of energy versus total elongation as shown in Fig. 1. Such a curve agrees very closely with a logarithmic function.

A second method is based upon the energy per unit volume displaced or upon its reciprocal, the volume displaced per unit energy. Referring to Fig. 2, *a b c d* is considered as the volume of metal displaced in rolling from length l_1 to l_2, that is, the volume

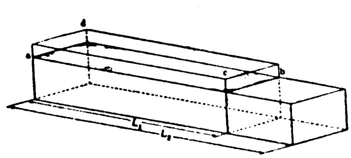

Fig. 2

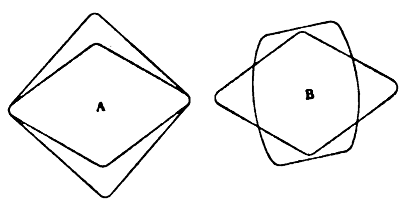

Fig. 3

of metal displaced is the product of the reduction in area and the original length.

The method used by the author consists in the application of a certain tangential force at the circumference of the rolls per unit reduction or transposition of sectional area. The following analysis will make this clear:

Referring to Fig. 3, two distinct kinds of rolling are represented

by A and B respectively. In case A, the reduction in area is the arithmetical difference of the two areas involved, while in case B, the transposition in area may be considered equal to that area of the one section which is not included within the outline of the other. Case A is by far the more common in rolling work. A combination of A and B may occur in certain forming passes where there is a slight reduction in area. Case B does not cause an elongation in the material but may be reduced to terms of an equivalent elongation when considering the total energy. This will become apparent in what follows.

Let l_1 = length of ingot at start of rolling
A_1 = sectional area of ingot at start of rolling.
l_2 = length of finished product.
A_2 = sectional area of finished product.
e = elongation per pass. e_s = total elongation.
N = number of passes.

Then

$$e_s = \frac{l_2}{l_1} = \frac{A_1}{A_2} \text{ and } e = \sqrt[N]{e_s} = \sqrt[N]{A_1/A_2}$$

assuming for the purpose in hand that there is no increase in density, nor loss of material and that the elongations in each pass are equal, which assumption will do for preliminary considerations.

Now if K be the force per unit reduction in area for any one pass, say the N_oth, R the effective radius of the rolls, and T the torque necessary for rolling, T will be given by

$$T = K\,R\,(A_{No-1} - A_{No}) = K\,R\,A_1\left(\frac{1}{e^{No-1}} - \frac{1}{e^{No}}\right) \quad (1)$$

Now

$$l_0 = l_1\,e^{No}$$

and since energy is the product of force and distance through which the force acts, the energy for the N_oth pass is

$$E_o = K\,l_1\,A_1\,(e - 1) \quad (2)$$

and the total energy for rolling is equal to

$$E = (\Sigma\,K)\,[l_1\,A_1\,(e - 1)] \quad (3)$$

since (**2**) is dependent upon the number of the pass only in so far as K is dependent. If K_o be taken as an average value of K over the conditions of ordinary rolling, W the weight of the ingot which is proportional to $l_1 A_1$, and E the total energy for rolling, then

$$E = N K_o W (e - 1) \qquad (4)$$

From large numbers of tests the h. p.-sec. per ton $\frac{E}{W}$, for different values of e_s have been determined for various sections.

The factor K_o varies with the temperature of rolling and diameter of the rolls as well as with the kind of steel and shape of the section rolled. Within the limits of practise, however, K_o as calculated from the above; *i. e.*

$$K_o = \frac{E}{W} \times \frac{1}{N (e - 1)} \qquad (5)$$

changes very little owing to the first three causes mentioned and rather less than might be expected due to the fourth. For example in a certain reversing-cogging-mill rolling 4-in. by 4-in. billets from three-ton ingots, K_o has a relative value of 3.2 compared with a value of 4.0 for a merchant mill rolling 3-in. channels from 6-in. by 6-in. billets. In the former case 22 passes are employed; in the latter 15. The two examples present totally different conditions of rolling. Of course in finding the total energy consumption per ton, the mill and motor losses must be added to the energy required for rolling.

If $\frac{E}{W}$ represents the units per ton which are being expended to roll steel having a total elongation of e_s in N passes, then K_o as given in (**5**) is a measure of the efficiency with which the rolling is being accomplished.

Table I gives a few typical values of K_o.

From the above it will be noted that the change in area in any pass is

$$A_1 \left(\frac{1}{e^{No-1}} - \frac{1}{e^{No}} \right)$$

and the length of the entering billet or ingot is given by $l_1 \, e^{No-1}$

TABLE I

Type of Rolling	Original section	Final section	Elongation	No. of passes	h. p.-sec. per ton for rolling	Av. K_O
Ingots to Billets	20 in. x 20 in.	6 in. x 6 in.	11.1	15	60,500	23.2 x 10^3
Ingots to Billets	20 in. x 22 in.	4 in. x 4 in.	27.5	23	85,000	23.8 "
Billets to Bars	5 in. x 5 in.	1.5 in. x 1.5 in.	11.1	12	89,000	23.6 "
Ingots to 70-lb. Rails	16 in. x 16 in.	7.2 sq. in.	35.6	23	120,500	31.2 "
Billets to channels	5 in. x 5 in.	1¼ in. x ⅜ in. x ¼ in.	40	17	16,450	39.9 "
Billets to *T* bars	5 in. x 5 in.	2 in. x 2 in. x ¼ in.	24.6	13	14,100	38.8 "
Sheet Mill	3 in. x 28 in.	45-in. sheets, 11 in. thick.	27.25*	17	144,000	39.5 "

*For simplicity in this case *e* has been taken as the ratio of the original to the final thickness of the sheets.

It should be noted that the values of K_O as given have not been reduced to a common temperature but represent typical conditions as found in practise.

Therefore, the volume of metal displaced in the N_oth pass is

$$l_1 e^{No-1} A_1 \left(\frac{1}{e^{No-1}} - \frac{1}{e^{No}} \right) = V\left(1 - \frac{1}{e}\right)$$

where V is the original volume.

This would show that under the assumed conditions the volume displaced per pass (see Fig. 2) is a constant value, and if K_1 is the energy per unit volume and $\frac{E}{W}$ the energy per unit mass,

$$K_1 = \frac{E}{W} \times \frac{\rho}{N\left(1 - \frac{1}{e}\right)}$$

where ρ is the average density of the metal.

From the foregoing it follows that

$$\frac{K_o}{K_1} = \frac{1}{\rho\, e} \tag{6}$$

Since e varies slightly for different conditions, equation (6) gives an idea of the discrepancies which will occur between a calculation in which K_o is taken as a given value, and one in which K_1 is the factor assumed.

K_o conforms to the method of "force per unit area" while K_1 applies to the method of "energy per unit volume displaced" under the same conditions.

With an average value of e determined upon, the number of passes required to roll any given section would be

$$N = \frac{\log A_1 - \log A_2}{\log e}$$

$$= \frac{\log e_s}{\log e}$$

Upon laying out the individual passes it may be necessary to modify e somewhat. Then too, if there is a large temperature drop from start to finish, K_o should vary from pass to pass ac-

cordingly. For changes in temperature the writer has derived the following empirical expression, which although not exact is very useful when used within ordinary temperatures for rolling steel.

$$K_o = C \log \frac{\theta_m}{\theta}$$

where

θ_m = temperature at which the metal liquefied in deg. cent., generally about 1380 deg.

θ = temperature of rolling in deg. cent.

For cold rolling the energy required for various materials may be taken as about proportional to the moduli of elasticity of the materials.

As previously pointed out K_o must also be modified to correspond to the shape of the section. A good idea of the values to apply in the individual passes can be obtained from the average value of K_o for rolling different sections.

In this connection it should be remembered that in certain forming passes there will be a transposition or shifting of sectional area without a corresponding volume displacement or elongation and K_o will be altered accordingly. However, what interests the electrical engineer is the aggregate result rather than what may happen in any one pass and this aggregate may be very accurately determined from the average value of K_o for any particular type of section rolled.

Should there be considerable transposition of section K_o as found in the ordinary way will be larger than usual. In such a case transposition may be considered as a certain hypothetical elongation.

With this method all types of rolling may be compared on the same basis.

Relation of Mill Speed to Tonnage

Let W = weight of each ingot in tons

S = tonnage per hour required.

$$\left.\begin{array}{l} t_i = \text{total time of intervals; seconds} \\ t_r = \text{total time of pass; seconds} \end{array}\right\} \text{for one ingot.}$$

Then

$$t_r = \frac{3600\ W}{S} - t_i$$

Now if l_1 = original length of ingot
N_o = number of the pass
d = effective diameter of the rolls
n = average rev. per min. during a pass
t_p = time of the pass,

then

$$t_p = \frac{60\, l_1\, e^{N_o}}{\pi\, d\, n}$$

and

$$t_r = \frac{60\, l_1}{\pi\, d\, n} [e + e^2 + e^3 + e^4 + \ldots\ldots e^N]$$

from which

$$n = \frac{60\, l_1\, [e^{N_o+1} - e]}{\pi\, d\, [e - 1] \left[\frac{3600\, W}{S} - t_i\right]}.$$

N is generally limited by the speed at which the material may be handled. In this case with n known, S is found from

$$S = \frac{3600\, W\, n}{\frac{60}{\pi} \times \frac{l_1}{d} \left[\frac{e^{N+1} - e}{e - 1}\right] + t_i\, n}$$

or with n and S both known, an insight into the rapidity with which the material must be handled may be found.

Fig. 4 shows a graphic application of the formula which is useful in obtaining an idea of the tonnage which any continuous-running mill may deliver.

The results obtained with a reversing mill are quite different. The calculated torque-time diagram for a typical reversing mill is given in Fig. 5. In this case the accelerating time in the pass is about one-half the time of the pass and the material is discharged from the rolls at top speed. The time of reversing and attaining the "nipping" speed is here included in the time of the interval.

Let T_p = turns in pass.
n_1 = nipping speed in pass
N_o = number of the pass
n = Max. speed in pass
t_p = time in pass seconds
t_a = acceleration time in pass.

Now it is good practise to make $n_1 = \frac{1}{3}\, n$ and $t_a = \frac{1}{2}\, t_p$.

Then

$$n = \frac{72\,T}{t_p}$$

$$= \frac{72}{\pi} \times \frac{l_1}{d} \times \frac{e^{No}}{t_p} \qquad n = \frac{72}{\pi} \times \frac{l_1}{d} \times \frac{e^{No}}{t_p}$$

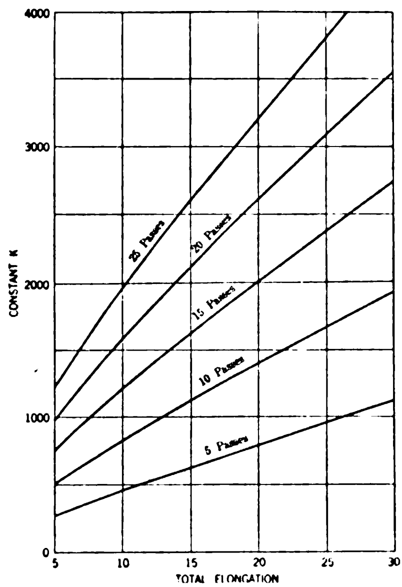

FIG. 4

NOTE: To find the total time in seconds for billet to pass through the rolls add to the time of the intervals the time T, when

$$T = \frac{L_1}{D} \times \frac{K}{n}$$

$\frac{L_1}{D}$ the ratio of the original length of the billet to the effective diameter of the rolls.

$\frac{K}{n}$ the constant from the curve divided by the average rev. per min. of the rolls.

Let the time of first pass $= t_1$
Let the time of final pass $= t_f$
Nipping speed in first pass $= n_1$
Nipping speed in final pass $= n_f$
Then

$$t_f = t_1 \times \frac{n_1}{n_f} \times e_s = K_2\,t_1 \text{ where } K_2 = \frac{n_1}{n_f} \times e_s$$

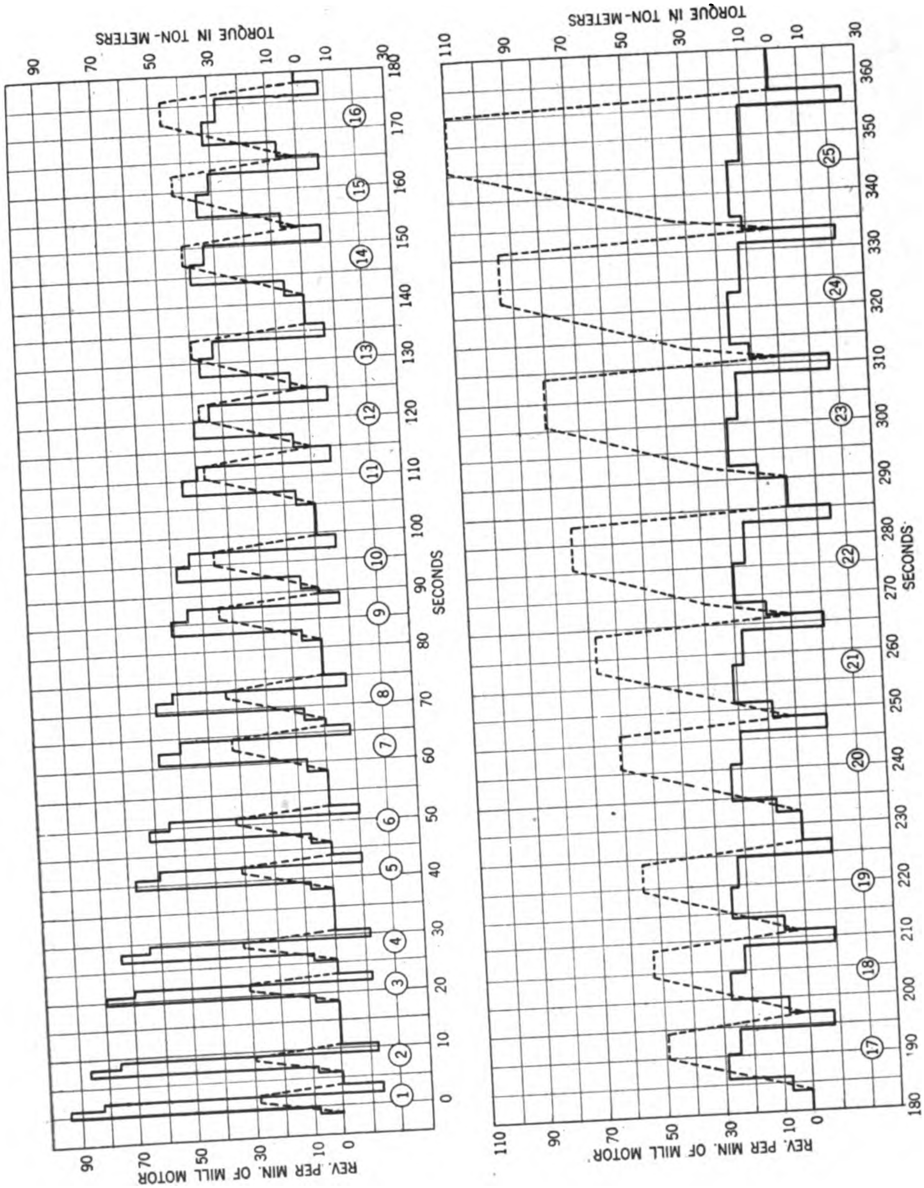

FIG. 5

and assuming that the times are in geometrical progression the total time of the N passes, t_r, is given by

$$t_r = \frac{\sqrt[N-1]{(t_1 K_2)^N} - \sqrt[N-1]{t_1^N}}{\sqrt[N-1]{t_1 K_2} - \sqrt[N-1]{t_1}} = t_1 \left[\frac{K_2^{\frac{N}{N-1}} - 1}{K_2^{\frac{1}{N-1}} - 1} \right] \quad (10)$$

and

$$t_1 = \frac{t_r (r-1)}{r^N - 1} \text{ where } r = \sqrt[N-1]{K_2} = \sqrt[N-1]{tf/t_1} \quad (11)$$

$$\text{also } t_{No} = t_1 r^{No-1} \quad (12)$$

The Determination of the Motor Capacity

For a continuous-running mill a good idea of the size of motor necessary may be obtained from the average value of torque, especially where heavy flywheels are employed and the fluctuations above and below this average are not severe. The r. m. s. rating of the motor will always be greater than its average output. This is considered more in detail under flywheel application as will be shown subsequently. In the case of a reversing mill the r. m. s. value of armature current may be taken safely as 10 to 15 per cent greater than that value of current which corresponds to the r. m. s. torque of rolling. This additional current is due

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to accelerating and retarding torque, friction torque, and to the increase in current per unit torque with field-weakening for the top speeds. This latter should not be over-emphasized, for field weakening takes place at relatively low values of torque.

To find an average value of torque,

From (1)

$$T_{No} = K\,R\,A_1 \left(\frac{1}{e^{No-1}} - \frac{1}{e^{No}} \right)$$

$$= K\,R\,A_1 \left(\frac{e-1}{e^{No}} \right)$$

$$\text{Also } t_p = \frac{60\, l_1\, e^{No}}{\pi\, d\, n} \quad \text{(for continuous mill)}$$

Therefore, torque $\times$ time for N_oth pass is

$$\frac{60\ K\ R\ A_1\ (e-1)}{\pi\ d\ n}$$

Now t_i = total time of intervals

t_r = total time of passes, $t_\Sigma = t_i + t_r$

$\therefore$ Average torque, T_a

$$T_a = \left[\frac{60\ K\ R\ A_1\ (e-1)}{\pi\ d\ n\ t_\Sigma}\right] N$$

Where N is the total number of passes, and since $d = 2R$

$$T_a = \left[\frac{30\ K_o\ A_1\ (e-1)\ N}{\pi\ n\ t_\Sigma}\right] \qquad \textbf{(13)}$$

To this torque is added the average friction torque to find the average torque exerted by the motor.

To find the r. m. s. torque,

Let $K\ R\ A_1\ (e-1) = c_1$

Then

$$T^2 = \frac{c_1^2}{e^{2\ No}}$$

and for a reversing mill,

$$t_{No} = t_1\, r^{No-1}$$

[see (**12**) above.]

Therefore torque-squared-time for the N_oth pass is

$$\frac{c_1^2\ t_1}{e^2}\left(\frac{r_o}{e^2}\right)^{No-1}$$

and $\Sigma\ T^2\ t$ for N passes is

$$\frac{\Sigma\ c_1^2\ t_1}{e^2}\cdot\left[\frac{\left(\frac{r}{e^2}\right)^N - 1}{\frac{r}{e} - 1}\right]$$

which gives

$$\text{r. m. s. } T = \frac{\Sigma c_1}{Ne} \sqrt{\frac{t_1}{t_\Sigma}\left[\frac{\left(\frac{r}{e^2}\right)^N - 1}{\frac{r}{e^2} - 1}\right]}$$

If torque is in kg-m. then

$$\text{r. m. s. kg-m.} = 38\,\frac{d}{l_1}\,W K_o\,\frac{e-1}{e}\sqrt{\frac{t_1}{t_\Sigma}\left[\frac{\left(\frac{r}{e^2}\right)^N - 1}{\frac{r}{e^2} - 1}\right]}$$

Where $d =$ diameter of rolls

l_1 = original length of ingot.
W = weight of ingot in tons.
K_o = constant for rolling (force per unit reduction.)
t_1 = time of 1st pass.
t_Σ = time of cycle.
$r = \sqrt[N-1]{K_2}$
$e = \sqrt[N]{e_s}$

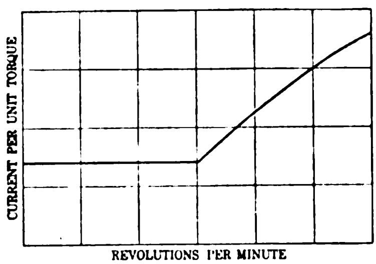

Fig. 6

In applying the above formulas it will be found that the torques in the first passes will be excessive and those in the last smaller than actually occur in practise. When a diagram is constructed the necessary corrections should be applied. As previously stated however, the aggregate result is what is most desired and within ordinary limits that is not greatly affected by what may happen in any one pass.

After torque-time and speed-time curves have been prepared for the mill-motor a current-time curve is drawn. This is determined from a motor characteristic curve which gives current per unit torque versus speed, as shown by Fig. 6. The output of the mill-motor is given for every instant by the product of the torque and speed curves, and to this output are added the losses which are easily determined from the above curves.

In this manner are found the energy diagrams for the generators of the Ilgner sets, as well as the exciter sets. The rating of these

machines is obtained by finding the r. m. s. value of current for armature and field circuits and in some cases the average iron

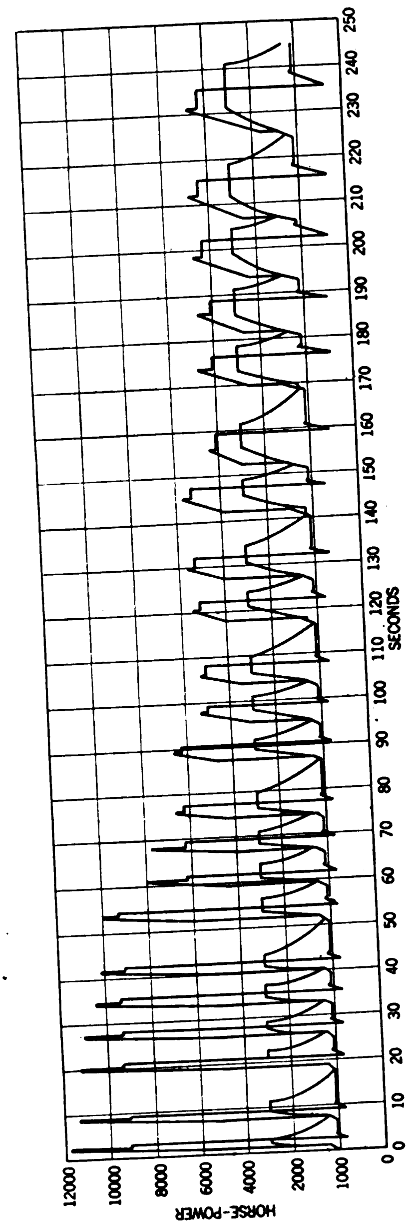

FIG. 7

losses throughout the cycle of operation. A typical "h. p.-time" diagram for a reversing mill is given in Fig. 7.

Flywheel Application

After a power-time diagram has been determined upon for a continuous mill or for the Ilgner set of a reversing mill the next step is the calculation of size and weight of wheel. In this it may

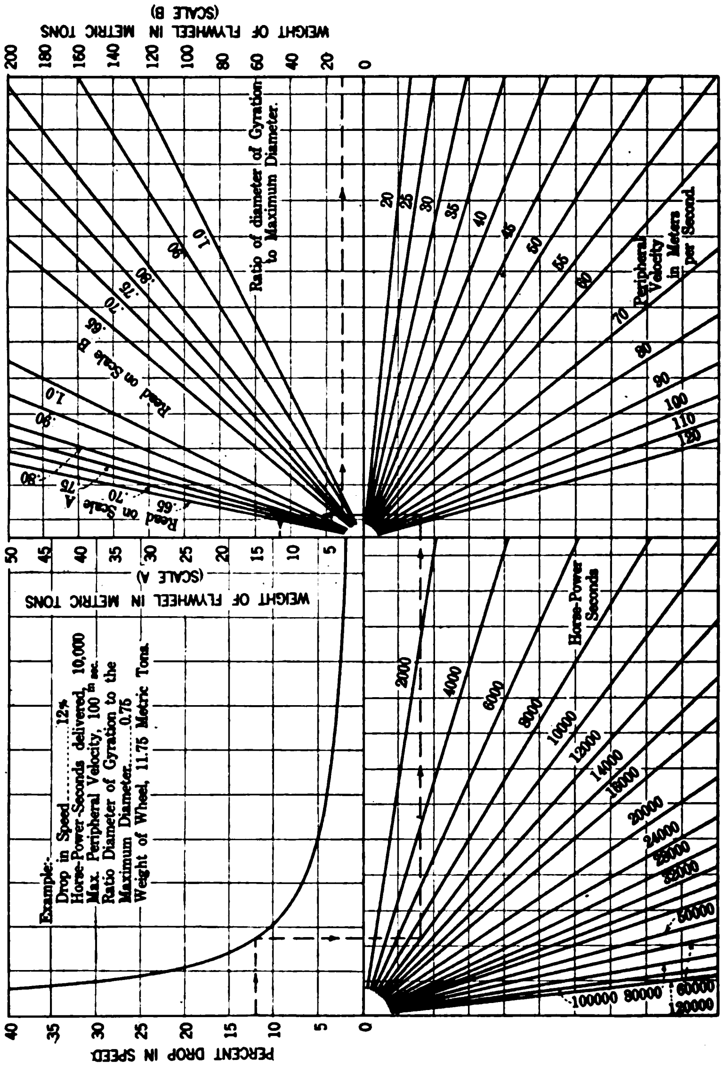

Fig. 8—Chart for Determining Weight of Fly Wheel

be assumed that all peak loads above the average will be carried by the wheel and that energy will be returned during the intervals in which the load is below the average. The amounts of energy which the flywheel must supply (both positive and negative) are

added algebraically one at a time for a complete cycle of retardation and acceleration to the original speed. The largest numerical value is taken as that which the flywheel must supply with a given speed drop.

The necessary weight of wheel may be obtained from

$$W = \frac{C\,E}{K_3^2\;V^2\,(2-d)\,d} \tag{1}$$

where

W = weight of wheel.
E = energy delivered with total drop in speed.
K = ratio of diameter of gyration to maximum diameter
V = maximum peripheral velocity of rim.
d = fractional drop in speed.

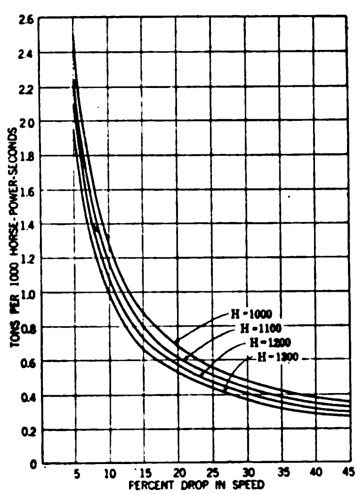

FIG. 9

Thus if E is in horse-power-seconds, V in meters per second and d in per cent drop in speed divided by 100, W will be in metric tons for a value of C equal to 1.491. A graphical application of the formula is shown in Fig. 8, by means of which an idea of fly-wheel weight may readily be obtained.

A very useful way of expressing flywheel efficiency is by the vertical height to which the intrinsic energy of the wheel would lift its weight when running at maximum speed. Fig. 9 gives a ready method of obtaining the weight of the wheel necessary for various designs.

The equation just given shows something which is often not apparent, namely that the speed of the flywheel shaft does not enter into the weight of wheel necessary, provided that the wheel be so designed as to get the maximum allowable stresses in the rim.

At this point it should be stated that there are many other factors which might influence the size of wheel selected. For example if an induction motor with slip-regulator is used, increasing the weight of the wheel means not only an increase in capital outlay, but also in constant losses. To offset this there

may be a reduction in size of the motor due to a more constant output; less loss in the slip-regulator and consequently a smaller one. The generators may be designed for a smaller variation in speed and the maximum demand from the line may be reduced. In each problem the total cost of these factors in pounds sterling (or dollars) per annum should be made a minimum. Fig. 10 illustrates the effect upon the motor peak load caused by a change of flywheel weight or the speed characteristics of the motor.

The opinion is often expressed that a mill cannot have too large a wheel. The writer has in mind a merchant mill where half the output of the motor is used continuously to keep an excessively large flywheel running with the result, incidentally, that the full-load output has never been reached.

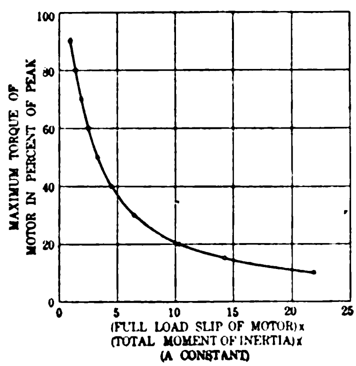

FIG. 10

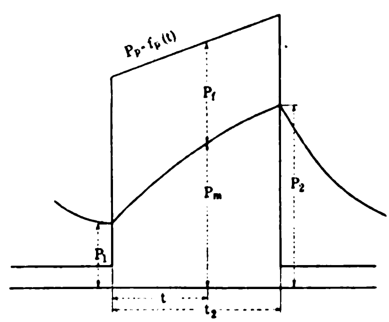

FIG. 11

Referring to Fig. 11

Let P_p = power of the peak load.

P_m = power from the driving motor.

P_f = power from the flywheel.

In general the above quantities can be expressed as follows:

$$P_p = f_p\ (t)$$
$$P_m = f_m\ (n)$$
$$P_f = I_n \frac{d\,n}{d\,t}$$

where t stands for time and n for the speed of the flywheel set. The function $f_p\ (t)$ is obtained from the power-time curve to which the flywheel set is to be applied and $f_m\ (n)$ from the speed characteristics of the driving motor.

Then the differential equation which shows that the instantaneous rate of transfer of energy to the generators (or to the mill) is equal to the algebraic sum of the power from the motor and that from the flywheel is given by

$$P_p = P_m \pm P_f \tag{2}$$

Now a very common application is that in which $f_p\ (t)$ is a constant value for a given interval of time and in which the torque of the motor is proportional to its drop in speed (or slip in the case of an induction motor), that is

$$P = K\ (n_0 - n)\ n \pm I\ n\ \frac{d\,n}{d\,t} \tag{3}$$

Equation (2) integrated from speeds n_1 and n_2 corresponding to power outputs of the motor P_1 and P_2, gives

$$t = \pm \frac{I}{2\,K}\left[\log \frac{P - P_1}{P - P_2} + \frac{1}{m} \log \left(\frac{1 - \dfrac{2\,n_1 - n_0}{n_0/2\,(m - 1) + n_1}}{1 + \dfrac{2\,n_2 - n_0}{n_0/2\,(m - 1) + n_2}} \right)\right] \tag{4}$$

in which $m = \sqrt{1 - \dfrac{4\,P}{K\,n_0^2}}$ and n_0 is the synchronous speed of the motor.

For all ordinary calculations the second term in the above equation may be taken as equal to the first. Making this assumption, we have

$$P_2 = P - \frac{P - P_1}{e^{\frac{K}{I}\,t}} \tag{5}$$

when the flywheel is decelerating, and

$$P_2 = P + \frac{P_1 - P}{e^{\frac{K}{I}\,t}} \tag{6}$$

when the wheel is accelerating.

From the differential equation it will be seen that all terms are expressed as power. Therefore in the case of an induction motor K will be given as $K = \dfrac{P}{n \times s}$ where P is the horse-power output of the motor at speed n and slip s (both in rev. per min.). I is a constant times the moment of inertia of the fly-wheel. Its value may be obtained from $I = \dfrac{2\,E}{n^2}$ in which E is the kinetic energy of the wheel in horse-power seconds when the speed is in revolutions per minute.

From this the time constant

$$I/K = 2\left(\frac{E \times s}{n \times P}\right) \qquad (7)$$

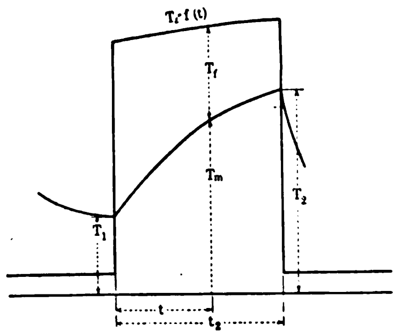

FIG. 12

in which as before E is the kinetic energy of the flywheel at n rev. per min. and P is the power output of the motor with slip s and speed n. Where there are heavy peaks of long duration $\dfrac{I}{K}$ will have a value of many seconds, depending also of course, upon the allowable drop in speed. On the other hand $\dfrac{I}{K}$ may be only a fraction of a second when the peaks are of short duration and infrequent.

Very often the torque instead of the power which is supplied by the motor and flywheel may be expressed as a function of the time or a constant value. Thus in the example illustrated in Fig. 12

$$c_1 + c_2\,t = T_m + T_f$$

$$= (n_0 - n)\,K' \pm I'\,\frac{d\,n}{d\,t} \qquad (8)$$

or

$$T = c_1 + c_2 t - c_2 \frac{I'}{K'} + \left(T_1 + c_2 \frac{I'}{K'} - c_1\right) e^{-\frac{K'}{I'} t} \tag{9}$$

or in general if $T_p = f(t)$

$$T = e^{-\frac{K'}{I'} t} \left[\int \frac{K'}{I'} f(t)\, e^{\frac{K'}{I'} t} \, dt + K_1 \right] \tag{10}$$

If T_p is a constant value, then

$$T = T_p - \frac{T_p - T_1}{e^{-\frac{K'}{I'} t}} \tag{11}$$

when the wheel is accelerating, and

$$T = T_p + \frac{T_1 - T_p}{e^{-\frac{K'}{I'} t}} \tag{12}$$

when the wheel is decelerating.

The time constant $\frac{I'}{K'}$ in this case corresponds to $\frac{I}{K}$ in the previous discussion. K' is the torque per rev. per min. drop in speed and I' is the torque necessary to accelerate the wheel one rev. per min. per unit time.

In other words $\frac{I'}{K'}$ is the time required for the motor when exerting a constant torque, (assuming that this be possible) to accelerate the wheel over a range of speed which is equal to the drop below synchronous speed necessary to produce this torque in the motor.

When an induction motor is used in conjunction with a slip regulator the current to the motor is limited to a fixed maximum value. Accordingly when the maximum torque of the motor has been reached equation (**3**) is modified to read

$$P = K'' n \pm I \frac{dn}{dt} \tag{13}$$

the solution of which gives

$$t = \frac{I}{K''}(n_1 - n_2) - \frac{I}{(K'')^2} P \times \left(\log \frac{P - K'' n_1}{P - K'' n_2} \right) \tag{14}$$

K is the ratio of the h. p. output of the motor to its speed in rev. per min. when the slip regulator comes into action.

If we are working with a torque-time diagram, equation (8) becomes

$$T_m \pm I \frac{dn}{dt} = c_1 + c_2 t \tag{15}$$

from which

$$\pm (n_1 - n_2) I' = (c_1 - T_m) t + \tfrac{1}{2} c_2 t^2 \tag{16}$$

When a flywheel curve has been plotted, the losses in the slip regulator may be obtained, the average value of which determines the size of the regulator. The losses in the driving motor are added to the ordinates which give the output of this motor and from the area of the resulting curve are found the required units per ton. In plotting flywheel curves, or in solving any of the equations given in which exponentials occur, the use of a log-log-slide-rule is recommended.

PROCEEDINGS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS

Vol. XXXVII Number 4

APRIL, 1918

Pittsburgh—New York April Meeting.

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PROCEEDINGS

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

IMPORTANT NOTICE

CHANGE OF DATE

As we go to press announcement has been received that the date of the meeting in Pittsburgh has been changed from April 9, as given elsewhere in this issue, to

WEDNESDAY, APRIL 10, 1918.

American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVII **APRIL, 1918** **Number 4**

A.I.E.E. PITTSBURGH—NEW YORK MEETING APRIL 9 and 12, 1918

The 339th meeting of the American Institute of Electrical Engineers will be an inter-section meeting, in Pittsburgh, April 9, and in New York, April 12, 1918. The Pittsburgh meeting will be held in the Chamber of Commerce Building, Pittsburgh, at 8:00 p. m., and the New York meeting at the Engineering Societies Building, at 8:15 p. m.

The same papers will be presented at both meetings and are as follows:

No load Conditions of Single-Phase Induction Motors and Phase Converters, by R. E. Hellmund.

A Physical Conception of the Operation of the Single-Phase Induction Motor, by B. G. Lamme.

For the convenience of members and guests in attendance at the New York meeting, a buffet dinner will be served prior to the meeting, in the Engineering Societies Building. Price, 85 cents per person, "pay-as-you-enter." This feature of the meeting will be in charge of the New York Membership Acquaintance Committee; and as the designation of the committee indicates, the purpose of this informal dinner is to meet the need of providing an opportunity for members of the Institute to become acquainted with each other. In the past various plans have been tried of providing opportunities for members to dine together prior to Institute meetings at conveniently located hotels and restaurants; but it is believed that the plan now proposed of an informal buffet dinner served in the same room in which the Institute meeting is to be held, will prove much more popular; and if the results justify such action, it is expected that similar arrangements will be made in connection with many of the future Institute meetings in New York.

It is well recognized that one of the greatest advantages of membership in any organization should be, opportunities for those interested in the same objects and ideals to become acquainted. It is hoped that all those who share this view will show their interest by attending this informal dinner, which will be served at 6:30 p. m. As the committee must make a guarantee to the caterer (the price of 85 cents being based on a minimum of 100 persons), it will be necessary to know as closely as possible how many will attend, and a return card will be mailed for this purpose to each member in New York and vicinity prior to the meeting.

FUTURE A. I. E. E. MEETINGS

May Meeting: The May meeting will be the Annual Business Meeting held at Institute headquarters, New York. At this meeting the annual report of the Board of Directors will be presented, and announcement made of the Election of officers for the ensuing year. The feature of chief interest at this meeting will be the ceremonies in connection with the presentation of the Edison Medal. A committee has been appointed to arrange the details of the presentation ceremonies and the complete program will be published in the May PROCEEDINGS

Annual Convention: It has been decided to hold the 34th Annual Convention of the American Institute of Electrical Engineers at the Marlborough-Blenheim Hotel, Atlantic City, N. J. on June 26, 27 and 28, 1918. Six technical sessions are contemplated.

The convention will open at 10:30 a.m. on Wednesday June 26 with the President's Address. This will be followed by the Technical Committee Reports. An informal reception will be held that evening.

The tentative program for the convention was decided upon by the Meetings and Papers Committee at the regular meeting in Cleveland March 8. The following papers are considered as convention possibilities and will be presented if they are submitted and accepted by the committee on or before April 25:

Wednesday, June 26, 2:30 p.m.—*Split-Conductor Cables—Balanced Protection*, by Wm. H. Cole; *Overhead Transmission Cables*, by E. B. Meyer; *The Application of Theory and Practise to the Design of Transmission Line Insulators*, by G. I. Gilchrist; *Wood Stick Insulators*, by H. H. Cochrane.

Thursday, June 27, 10:30 a.m.—*Lightning Arrester Spark Gaps*, by C. T. Allcutt; *The Oxide Film Lightning Arrester*, by C. P. Steinmetz; *Design of Transpositions for Parallel Telephone and Power Circuits*, by H. S. Osborne.

Thursday, June 27, 2:30 p.m.—Members and Section Delegates Conference.

Thursday, June 27, 8:30 p.m.—*Fixation of Nitrogen* by E. Kilburn Scott; *America's Power Supply*, by C. P. Steinmetz; *Cooperative Electrical Engineering Course*, by D. C. Jackson and M. W. Alexander.

Friday, June 28, 10:30 a.m.—*Precharged Condensers*, by V. Karapetoff; *Method of Symmetrical Coordinates Applied for the Solution of Polyphase Networks*, by C. L. Fortescue; *Flux Distribution in Alternators Under Sustained Short-Circuit Conditions and Different Loads*, by N. S. Diamant.

Friday, June 28, 2:30 p.m.—*Protection from Flashing in D-C. Apparatus* by J. J. Linebaugh and J. L. Burnham; *The Automatic Hydroelectric Plant*, by J. M. Drabelle and L. B. Barnett.

FUTURE SECTION MEETINGS

Baltimore.—April 12, 1918. Subject: Operation of Hydroelectric Stations.

Cleveland.—April 22, 1918, Subject: Storage Battery Charging.

Ithaca.—April 26, 1918. Subject: Resuscitation from Electric Shock.

Madison.—April 9, 1918. Subject: Four-Wire Three-Phase Power and Light Distribution.

Philadelphia.—April 8, 1918. Engineers Club. Subject: Electrification of Railroads in Its Relation to Communication Lines.

April 25, 1918, Franklin Institute. Speaker, Charles P. Steinmetz. Subject: High-Tension Phenomena and Power Transmission.

San Francisco.—April 26, 1918. Speaker: E. R. Shepard. Subject: Electrophysics.

Schenectady.—April 5, 1918. Speaker, Lieut. Col. N. H. Slaughter. Subject: Radio Communication.

Spokane.—April 19, 1918. Subject: Acceptance Test of Hydraulic Turbines.

Toronto.—April 5, 1918. Speaker, W. P. Dobson. Subject: High-Voltage Testing.

April 19, 1918. Speaker, P. Ackerman. Subject: High-Tension Insulators from the Operating Viewpoint.

A. S. C. E. MEETING

On April 3 at 8:30 p. m. a regular meeting of the A. S. C. E. will be held at the Engineering Societies Building, 33 West 39th St., New York. At this meeting George W. Fuller will give an informal talk on "Emergency Construction Work Due to War Conditions," illustrated with lantern slides. Mr. Fuller has been in close touch with this work, particularly cantonment con-

struction, and will present some practical lessons taught by actual experience.

Members of the A. I. E. E. are cordially invited to attend this meeting.

THE 338th INSTITUTE MEETING IN CLEVELAND

The 338th meeting of the Institute was an intersection meeting held in the Electrical League Club Rooms, Hotel Statler, Cleveland, Ohio, March 8, in which the Cleveland, Pittsburgh, Toledo, Toronto and Detroit Sections of the Institute participated. Papers were presented at two technical sessions.

The afternoon session was called to order by President E. W. Rice, Jr. at 2:40 p.m. with an attendance of about 150. After calling attention to the fact that Cleveland was the home of Mr. Charles F. Brush, the inventor and manufacturer of the first commercial arc dynamo and the pasted type of lead storage battery, President Rice asked for the first paper entitled *Design of Underground Distribution for Electric Light and Power Systems*, by G. J. Newton. In the absence of the author Mr. F. M. Hibbin presented the paper and in the succeeding discussion the following men took part: A. A. Meyer, C. W. Rakestraw, H. L. Wallau, E. Friedlaender, E. B. Meyer, W. Sykes and F. M. Hibbin. The next paper entitled *Some Considerations in Determining the Capacity of Rolling-Mill Motors*, by Robert F. Hamilton was then presented in abstract by Wilfred Sykes in the absence of the author. The following men took part in the discussion: A. M. Dudley, C. A. Menk, N. W. Storer, J. D. Wright and W. Sykes.

The evening session was called to order by President Rice at 8:55 p. m. This was a joint session between the A. I. E. E. and the A. I. & S. E. E. and the attendance was about 150. The first paper of the session entitled *Selection of Steel Mill Auxiliary Motors and Control as Affected by Mechanical Features of the Drive* was abstracted by the author Mr. J. D. Wright. The following men took part in the discussion: E. Friedlaender, C. A. Menk, T. E. Tynes, H. S. Richardson, B. G. Beck, G. E. Stoltz and J. D. Wright. President Rice then presented Mr. C. A. Menk, President of the A. I. & S. E. E., who took the chair. He called on Mr. W. T. Snyder who presented his paper entitled *Steel-Industry Motors Standardized*. The following men took part in the discussion: T. E. Tynes, B. G. Beck, D. M. Petty, H. C. Cronk, M. W. Cobbledick, H. C. Cosdon, L. J. Hess, E. Friedlaender, R. D. Nye, R. W. Knowles, E. W. Rice, Jr., and W. T. Snyder.

Between the afternoon and evening sessions an informal dinner was held at 6:30 p. m. The principal speaker at the dinner, Mr. Ambrose Swasey, laid particular stress on the responsibility that will devolve upon the engineer after the war is over. He stated that as it is engineering achievements that are making the war so terrible, after the war it must be the engineer's object to make civilization safe. Mr. Swasey was followed by Mr. Charles F. Brush who pointed out in particular the achievements of American engineers as compared with those of the other countries.

The regular monthly meeting of the Board of Directors of the Institute, an account of which is given elsewhere in this issue, was held previous to the afternoon technical session. This meeting was adjourned to meet in New York, March 15 at which time the following resolutions were proposed and adopted:

RESOLVED, that the Board of Directors of the American Institute of Electrical Engineers hereby expresses to the Electrical League of Cleveland, its appreciation of the courtesies extended by the League to the members of the Institute and others in attendance at the Institute meeting held in the headquarters of the League, Hotel Statler, Cleveland, March 8, 1918.

RESOLVED, that the Board of Directors of the American Institute of Electrical Engineers hereby expresses to the committee in charge of the arrangements for the Institute meeting in Cleveland, March 8, its appreciation of the excellent plans made by the committee and the manner in

which these plans were carried out, resulting in a profitable and enjoyable meeting for the members and guests in attendance.

DIRECTORS' MEETING, CLEVELAND, O., MARCH 8, 1918

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at the Hotel Statler, Cleveland, O., on March 8, 1918.

There were present: President, E. W. Rice, Jr., Schenectady, N. Y.; Vice-President, L. T. Robinson, Schenectady, N. Y.; Managers, N. A. Carle, Newark, N. J., Wilfred Sykes, Pittsburgh, Pa.; and Secretary, F. L. Hutchinson, New York.

Upon the recommendation of the Board of Examiners the following action was taken upon pending applications: 42 students were ordered enrolled; 144 applicants were elected to the grade of Associate; 6 applicants were re-elected to the grade of Associate; 7 applicants were elected to the grade of Member; 10 applicants were transferred to the grade of Member.

Various matters were discussed but it was decided to defer the transaction of other business and to hold an adjourned meeting of the Board of Directors at Institute headquarters in New York on Friday, March 15, 1918.

DIRECTORS' MEETING, NEW YORK, MARCH 15, 1918

An adjourned meeting of the Board of Directors was held at Institute headquarters on Friday, March 15, 1918, at 3:30 p. m.

There were present: Vice-Presidents, B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y., A. S. McAllister, New York; Managers, John B. Taylor, Schenectady, N. Y., Harold Pender, Philadelphia, Pa., Walter A. Hall, Lynn, Mass., William A. Del Mar, New York, C. E. Skinner and Wilfred Sykes, Pittsburgh, Pa.; Treasurer, George A. Hamilton, Elizabeth, N. J., and Secretary, F. L. Hutchinson, New York.

The actions taken at the meeting of the Board held in Cleveland on March 8, were approved.

The action of the Finance Committee in approving monthly bills amounting to $9,375.85 was ratified.

Upon the petition of Professor Merton M. Cory and with the approval of the Chairman of the Sections Committee, the organization of a student Branch at the Michigan Agricultural College, East Lansing, Michigan, was authorized.

A considerable amount of other business was transacted, reference to which will be found in this and future issues of the PROCEEDINGS.

SELECTION OF DIRECTORS' NOMINEES FOR OFFICERS FOR 1918-1919

At the adjourned meeting of the Board of Directors of the Institute held in New York on March 15, the report of the Committee of Tellers on the nomination ballots received for officers of the Institute for 1918-1919, as printed elsewhere in this issue, was presented. The Board then selected its list of Directors' Nominees for the offices to be filled at the annual election on May 17, 1918, in accordance with Section 31 of the Constitution, with the following result: For President, Comfort A. Adams, Cambridge, Mass.; for Vice-Presidents, William B. Jackson, Chicago, Ill., Harold Pender, Philadelphia, Pa., John B. Taylor, Schenectady, N. Y., F. B. Jewett, New York, N. Y., Allen H. Babcock, San Francisco, Cal., Raymond S. Kelsch, Montreal, Quebec; for Managers, Frank D. Newbury, Pittsburgh, Pa., G. Faccioli, Pittsfield, Mass., Walter I. Slichter, New York, N. Y.; for Treasurer, George A. Hamilton, Elizabeth, N. J.

The ballots were mailed to the Institute membership the latter part of March, and in order to be valid must

be returned in time to reach the secretary's office in New York not later than the first day of May.

REPORT OF COMMITTEE OF TELLERS ON NOMINATION BALLOTS

March 6, 1918

To the Board of Directors, American Institute of Electrical Engineers.

Gentlemen: This Committee has counted and canvassed, in accordance with Article VI of the Constitution, the nomination ballots received for officers of the Institute for 1918-1919. The result is as follows:

Total number of envelopes said to contain ballots, received from the Secretary		1066
Rejected on account of bearing no identifying name on outer envelope	37	
Rejected on account of having reached Secretary's office after Feb. 28	35	
Envelopes received containing no ballots	33	
Leaving as valid ballots		961

These valid ballots were counted and the result is shown below.

FOR PRESIDENT

Comfort A. Adams	910
Scattering and blank	51
Total	961

(The scattering vote was divided among 12 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR VICE-PRESIDENTS

William B. Jackson	903
Harold Pender	896
John B. Taylor	888
F. B. Jewett	887
Allen H. Babcock	885
Raymond S. Kelsch	858
Scattering and blank	449
Total	5766

(The scattering vote was divided among 40 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR MANAGERS

Frank D. Newbury	598
Morton G. Lloyd	569
Charles I. Burkholder	538
G. Faccioli	527
Walter I. Slichter	439
Scattering and blank	212
Total	2883

(The scattering vote was divided among 19 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR TREASURER

George A. Hamilton	843
Scattering and blank	118
Total	961

(The scattering vote was divided among 4 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

Respectfully submitted,

LOUIS WINTNER, *chairman*
F. V. MAGALHAES,
A. V. MERSHON,
G. E. SCHULTZ,
FRED P. WOODBURY,
Committee of Tellers.

ENGINEERING COUNCIL

Officers and Committees for 1918
Progress, Field and Aims

(*Extracts from a statement issued in February* 1918 *by Engineering Council*)

Engineering Council is an organization of national technical societies of America created to provide for consideration of matters of common concern to engineers, as well as those of public welfare in which the profession is interested, in order that united action may be made possible. Engineering Council is now composed of the American Society of Civil Engineers, American Institute of Mining Engineers, American Society of Mechanical Engineers and American Institute of Elec-

trical Engineers, having a membership of 33,000 and known as the Founder Societies.

Engineering Council held its first meeting June 27, 1917. In the months which have elapsed, useful services have been rendered to the Government, to engineering societies and to individuals, and progress has been made in perfecting Council's organization. Offices have been secured in the Engineering Societies Building, New York City, the focus of engineering activities in America. A permanent executive officer, with the title of Secretary, has been engaged; he entered upon his duties January 1. Several important committees have been created and have accomplished much.

February 21, 1918, the first annual meeting was held. The following officers were elected: *Chairman*, J. Parke Channing; *First Vice-Chairman*, Harold W. Buck; *Second Vice-Chairman*, George F. Swain; *Secretary*, Alfred D. Flinn. Committees were appointed as follows: *Executive Committee*, the Chairman, the two Vice-Chairman and David S. Jacobs, Calvert Townley, George J. Foran; *Finance Committee*, E. Wilbur Rice, Jr., Chairman, Charles F. Loweth, Sidney J. Jennings, David S. Jacobus; *Rules Committee*, J. Parke Channing, Chairman, Clemens Herschel, Nathaniel A. Carle, Irving E. Moultrop; *Public Affairs Committee*, Charles Whiting Baker, Chairman, George F. Swain, Benjamin B. Thayer, E. W. Rice, Jr., Charles E. Skinner. *American Engineering Service*, George J. Foran, Chairman, George C. Stone, Alfred D. Flinn, Addams S. McAllister, Edward B. Sturgis, secretary; *War Committee of Technical Societies*, D. W. Brunton, Chairman, Arthur H. Storrs, Secretary, James M. Boyle, Nelson P. Lewis, Edmund B. Kirby, A. M. Greene, Jr., R. N. Inglis, Harold W. Buck, Dr. Addams S. McAllister, Dana D. Barnum, E. C. Uhlig, Joseph Bijur, Dr. Chas. A. Doremus, Louis B. Marks, Preston S. Millar, Christopher R. Corning, George C. Stone, Henry Torrance, F. E. Matthews: *Fuel Conservation Committee*, L. P. Breckenridge, Chairman, Ozni P. Hood, Secretary, Robert H. Fernald, Charles R. Richards, Charles L. Edgar, Carl Scholz, David Moffat Myers, Edwin Ludlow, Harold W. Buck.

A Patents Committee, to investigate reforms in the U. S. patent system and in the use of experts in litigation wherein the validity of patents or other technical matters are involved, was also created, but the names of its members cannot yet be announced. The committee was instructed to co-operate with any committee of the National Research Council, and with committees of other technical societies organized for a kindred purpose.

Limitation of financial resources has been and still is one of the greatest handicaps. At the beginning of this year, an appropriation of $16,000 by United Engineering Society, contributed equally by the four Founder Societies became available for the period ending October 31, 1918. Although this sum provides for the usual expenses of the secretary's office, for inaugurating several permanent lines of service and for a few special items in connection with the war, it is far from adequate. Engineering Council is still forced to go slowly on work already undertaken and to decline or defer other meritorious projects.

Restriction of membership in Engineering Council to the four Societies just mentioned is not intended. It is planned and earnestly desired that other national engineering and national technical societies shall become affiliated, thus making Engineering Council truly representative of the hundred thousand engineers in all branches of the profession throughout the United States. Conditions and methods for the admission of additional Societies are being developed.

It has become evident that although numerous engineering societies are occupying limited fields efficiently, and although some of these fields are extensive, there are large sectors of the do-

main of the engineer which are either but weakly held, or else are usurped by others. This condition has arisen partly from specializing tendencies among societies as well as among individuals. Until the present time, there has been no central agency capable of entering these sectors and competent to speak for the profession at large,—no duly constituted representative to learn of the share in local civic and governmental enterprises which should be the engineer's, to claim it for him, and to see that he gets it; no organization to harmonize the action of the profession on similar questions in different localities; no interpreter to the public of the engineer, his work, his ideals and his methods; no body to develop meritorious projects for the general good of the profession or for the benefit of the public; no one constantly on guard to detect and oppose objectionable schemes and tendencies. To fill these gaps is the great aim of Engineering Council,—not by demolishing any useful existing agencies, but by building these into a well proportioned and thoroughly furnished structure.

COMPENSATION OF ENGINEERS

The following appeal for increased compensation of professional engineers and engineering assistants (distinguished from locomotive enginemen and other operatives of engines also called engineers) is an extract from a letter of February 28, 1918 by Engineering Council through Alfred D. Flinn, Secretary, to the Railroad Wage Commission appointed by the Director General of Railroads.

"The engineers and engineering assistants have no union or similar organization to urge increases of salaries or betterment of conditions as have the skilled and unskilled labor employees. It has been stated to Engineering Council that excepting a comparatively small number of individual cases, no increases in compensation to technical employees of railroads have been made since 1914, while within the same period large increases have been granted to skilled and unskilled labor. Owing to the depreciation of the dollar, these technical employees have, therefore, in reality suffered a great diminution in income. Applications for increases, even on the basis of the increased cost of living, have been refused them on the ground that they can be replaced and that they must stand war privation, although no such theory has been applied to the trainmen, who equally as individuals can be replaced. As a class, neither trainmen nor technical employees can be replaced at present. The discrepancy in compensation is indicated by such few statistics as we have in hand. Some of these are given below.

"Of 31 classes of Railroad employees concerning whom information is given in a letter dated February 13, from the Bureau of Railway Economics, quoting the Interstate Commerce Commission report for the year ending June 30, 1915, 12 classes on the average received more, and 18 classes less than the assistant engineers and draftsmen; the highest paid class (road passenger engineers and motormen) received nearly 100 per cent more. Road freight engineers and motormen, and road passenger conductors were paid about 66 per cent more; foremen, boilermakers, brakemen, firemen and helpers received approximately the same pay as the assistant engineers and draftsmen (some a few dollars more and others a few dollars less on the average). It is highly probable that if figures for 1917 were available it would be found that the pay of the assistant engineers and draftsmen was much less in proportion than in 1915.

"Below is a comparison between salaries paid a few engineers and draftsmen in the employment of one of the most important railroad systems of the country, having its terminus in New York City, and their compensations in positions to which they went from the railroad office.

Description of railroad position	Railroad Salary	Description of industrial position	Industrial Salary
Assistant engineer erecting power sub-stations	$160	In charge of erecting nickel reduction plants	$400
Chief draftsman	135	Chf. Engr. explosives company	325
Draftsman and ass't engr. in charge of construction	105	Ass't. Supt. power plant	275
Assistant engineer	160	Consulting engineer for wire company	350
Assistant engineer	160	Designing engineer for chemical company	200
Draftsman	100	Engr. U. S. Engineers	121
Assistant engineer	135	Ensign, U. S. N. in charge of projectile inspection	175

"The table of averages, the general statement, and the few specific examples given above must, of course, be considered in connection with many other data. Local conditions affect rates of pay. Railroad managements differ in their policies in this matter; some have fully or at least in a measure during the past year and a half met the conditions which have arisen. Rates of pay for steady employment with a railroad company, cannot be directly compared with rates for industrial engagements, often of limited duration, and involving extra expenses. All the necessary information is doubtless subject to your call. Engineering Council may be able to assist in collecting, supplementing and analyzing the data especially relating to civil engineer employees. It offers its services. Its desire is that the compensation of technical employees of the railroads of the country may receive full consideration and a fair determination.

"In conclusion, we would bring to your attention the fact, which must be known to you, that upon the intelligence skill, and efficiency of the technical engineers the maintenance, operation and progress of the country's railroad systems largely depends. These men deserve just compensation. In order to inspire them to the services which will yield the highest benefits to the community as well as to the railroads, they should receive liberal pay. An increase in their compensation is urgently called for by circumstances at this time."

THE DOINGS OF THE ELEVENTH (RAILWAY) ENGINEERS "OVER THERE"

BY ROSSITER W. RAYMOND

This regiment, originally known as the First Engineer Reserve, will be remembered as the one recruited in New York City through the efforts of the Joint Military Committee of the National Engineering Societies. It was sent to England in August, 1917, and, after a few days, forwarded to France and attached for immediate service to the British Expeditionary Force, without any opportunity for further field-training. This circumstance has led in some quarters to the impression that the regiment was one of engineers and mechanics merely, and had never been drilled under arms; whereas, in fact, it had received such instruction at Fort Totten for some time previous to its embarkation. It is true that in the famous affair of the German counter-attack after Byng's victory near Cambrai, the men of the Eleventh Engineers fought with pick-axes and tools, as well as with rifles borrowed from dead or wounded soldiers; but that was because they had left their own arms in camp, while doing the railroad-building work to which they had been detailed. The

accomplishment of that work is really more remarkable than the behavior of the men under a German surprise-attack.

It was before that counter-attack and immediately after Byng's advance that Field-Marshall Haig issued his despatch, announcing that the engineers deserved as much credit for that victory as the infantry, having performed miracles in keeping the railway-transportation up to the fighting-line.

Indeed, the subsequent scrimmage, of which so much has been said, was made possible only by the extraordinary position of the engineers at the very front, instead of in the rear, as might have been expected of them.

A letter recently received from an officer of the regiment says:

"We have only recently been receiving the New York papers of early December, in which our regiment seems to have received much favorable mention. The stories were, in the main, true. Our men behaved themselves creditably, and certain of the officers received special mention for valor. Two of our 2nd Lieutenants were promoted to 1st Lieutenant rank by special orders of General Pershing for 'gallant conduct in action,' and about four others would have been decorated by the British, if our laws permitted the acceptance of foreign decorations. It is too bad that it is so, for the British were very keen to do it; and as such honors go, these were well earned.

"The senior U. S. officer present was the senior captain of my battalion who was there with the bulk of his company with some detachments from two companies of the Second Battalion. He was 'cited' for going through the barrage three times to bring back groups of his men who were caught out along the track. The shortest man in the regiment is a little 2nd Lieutenant (one of those promoted) who was struck in the head by a bullet which went clean through both sides of his steel helmet, and chipped the upper edge of his forehead on the way. If he had been one quarter of an inch taller it would have finished him. He is now back from the hospital. He was hit while going down the track to collect his men. While he was being led back to the dressing station his only comment was an order to one of the men to go back and 'get that tin hat, 'cause I want to keep it.' He was put on a stretcher at the dressing station, and loaded on a narrow-guage rack-car to be transported to the C. C. S. (Casualty Clearing Station), and while lying there a Bosch aeroplane swooped down over the village and peppered everything in sight with a machine-gun, he lying on his back looking right up at it as it passed directly over him and shot down six Tommies just across the street. Another of our men, a Corporal, was wounded in three places before he got to the ambulance, and then as he lay in the ambulance got another bullet through the arm from an aeroplane, probably this same one.

"A story has reached us through the Tommies, that one of our men who was found dead on the field from bayonet wounds had three dead Germans in front of him, killed by the R. R. pick he had wielded valiantly. A wounded British officer reported that two of our men had been shot down while carrying him off the field, but we have never been able to find these men; perhaps they were only wounded and carried away as prisoners. There were 10 wounded and 18 missing, of whom we have since accounted for 3 as killed and 1 a prisoner in Germany. Since that things have been pretty quiet, though we have had a little excitement with aero-bombing parties now and then.

"Really, the fuss that has been made over our little incident is out of all proportion to the serious things going on about us all the time, and hardly given a second mention, so it makes us feel a little embarrassed. Of course, this incident was given prominence, because it was one of the first encounters in which American troops took part, and more particularly as they were

popularly supposed to be not trained for fighting (though they are, only they didn't have their guns with them on the work that day). But we ran up against British officers every day, who have come out of engagements with a mere handful of men, the remnant of a company or a battalion, and some of them have done it several times over. Nothing at all is made of it, for it is an old story with them.

"We do not know yet, nor can our public comprehend what it all means. It is as yet only a sort of thrilling moving-picture show. But there is no use talking, it is a great old show, even in the calm times like the present, and a trip along the road between my camp and the front gives one glimpses of men and things that would adorn many a tale if one had the pen to describe them, and old Mr. Censor would permit. When a little more time is passed, it may be proper for me to send you an account of what I saw the day of the 'big push,' when I followed out in the path of the tanks to a point way beyond the Hindenburg line, with the British batteries coming into position and banging away over my head, the German trenches full of Tommies in reserve, the thickets of barbed wire entanglements either trampled under foot by the steel monsters, or torn up by the roots, by their huge derricks, the pioneers clearing the felled trees from the highways, and finally the thrilling sight of the cavalry and the Indian Lancers going out to battle, many, many thousands of them, on *their day*, for which they had waited for three years!

"That was the day we got busy, and proceeded with the work we came here to do, that is, the special job we had been scheming for and dreaming of at night, and wondering which of the companies would be the lucky ones to be on the work. Well, we did the trick, and connected up with the ends of the Bosch R. R. tracks. This has, so far as I know, never been mentioned in any of the accounts, but to me is the real thrilling point to the whole episode, so far as our regiment achievements are concerned; for, for the first time in three years, there was through rail-connection established from Paris to Berlin! What more could we do to win the war? A fine straight road, but no one had the nerve to travel it! Well, that road lasted just about 18 hours. There are a lot of our tools out there yet that we can't recover, and perhaps some of the missing men—nobody knows.

"Some of the other American units over here think we are getting more than our share of honors, and perhaps we are. As a matter of fact, we were the first in the zone of the advance, and had the first casualties; and then came the little affair which brought us into the lime-light; until now I understand some envious wag down at Gen. H. Q. remarked, paraphrasing Mr. Dooley—'The ——th Engineers, *Alone in France*'!"

Another thing that the fighting engineers of the Eleventh have done deserves mention. At Christmas, the men of the first (Major Arthur S. Dwight's) battalion sent 10,000 cigarettes and a lot of smoking tobacco to Mrs. Dwight to be distributed by her among 1,000 French soldiers in a Paris hospital. Mrs. Dwight is a favorite with the battalion, having shown its members much hospitality at her mansion near Fort Totten on Long Island, before they went abroad; and this evidence of their affection and their sympathy with her work in Paris was accompanied with the message, "For our French brothers, hoping that they will enjoy the smoking as much as we do the giving!

One can understand a good deal of ordinary generosity among our fine fellows at the front; but to give away 10,000 cigarettes—now—in France!—really, it taxes credulity! Yet Maj. Dwight writes me that his men are still bringing in additional contributions, and that he will have to make another shipment of cigarettes before long.

A. I. E. E. HONOR ROLL

Members of the American Institute of Electrical Engineers in Army and Navy service with the United States and her Allies.

This list supplements those published in the four preceding numbers of the PROCEEDINGS and includes only those members who are in the armed forces and who have responded to the War Service card sent to the membership on Sept. 15, 1917, or have otherwise communicated with Institute head quarters.

Members in Army and Navy service who have not been listed are requested to furnish the Institute with their proper military designation.

ASHTON, OLIVER
Ensign, Aviation Corps, U. S. Navy.
CARTER, GEORGE R.
First Lieutenant, 303d Artillery.
EDWARDS, IRVING W.
First Lieutenant, Ordnance, R. C.
EGBERT, D V.
Ensign, U. S. N. R. F.
FEAR, LYLE G.
Lieutenant, junior grade, U. S. N. R. F.
FORNEY, ROSS H.
Lieutenant, Ordnance, R. C.
GRAHAM, ROBERT W.
Lieutenant, junior grade, U. S. N. R. F.
GRANT, LOUIS T.
Captain, Engineer, Camp Lee.
HAMILTON, C. P.
26th Engineers.
HOBART, C. M.
Aviation Section, Signal Corps.
HUTCHINSON, H. H.
Captain, Ordnance, R. C.
KAPLAN, EUGENE V.
37th Engineers.
KINKEAD, ROBERT E.
Lieutenant, junior grade, U. S. N. R. F.
MADDEN, MILTON F.
37th Engineers.
NODELL, WM. L.
Captain, Engineer, R. C.
OETINGER, HERBERT W.
U. S. N. R. F.
OWEN, N. J.
First Lieutenant, 30th Engineers.
POPP, C. M.
Lieutenant, junior grade, U. S. N. R. F.
PROUT, CURTIS
First Lieutenant, Engineer.
ROBBINS, JOHN F.
Lieutenant, junior grade, U. S. N. R. F.
RUSSELL, FLOYD L.
First Lieutenant, Coast Artillery R. C.
SEVER, GEORGE F.
Major, Engineer, R. C.
STAFFORD, J. W.
Sergeant, U. S. Radio School.
SWEITZER, L. E.
Signal Corps.
TAUSSIG, WARREN A.
Lieutenant, Field Artillery.
TERRY, R. H.
Coast Artillery Corps.
TOWNSEND, C. P., Jr.
First Lieutenant, 117th Engineers.
VON ROSENBERG, H. C.
Officers' Training Camp.
WILSON, J. L.
British Army.
WOODRUFF, W. W.
First Lieutenant, Ordnance, R. C.

SUMMARY OF MEN IN SERVICE

U. S. Army:

Brigadier Generals 2; Colonels 6; Lieutenant Colonels 3; Majors 52; Captains 137; First Lieutenants 154; Second Lieutenants 92; Sergeants 12; Corporals 7; enlisted men 100; miscellaneous 27. Total 592.

U. S. Navy:

Lieutenant Commanders 9; Lieutenants 9; Lieutenants, junior grade, 70; Ensigns 14; enlisted men 9; miscellaneous 24. Total 146.

British and French Armies 10.

Grand Total 748.

GOVERNMENT SERVICE

Engineers desiring to be of service to the Government will find an opportunity by bringing to the attention of young technical men, artisans, and others who may be interested in enlisting in an engineering unit, the organization at Washington Barracks, D. C., on December 14, 1917, of the First Replacement Regiment of Engineers, the specific purpose of which is to keep all engineering units of the Army at full enlistment strength during the period of the war. This regiment has not only the responsibility of finding men to fill up depleted ranks in the various units, but it must also fit the men to step into the work of trained, efficient and disciplined soldiers.

The engineer soldiers must know how to tie all the important kinds of knots and lashings, to build spar and truss bridges, to construct revetments, dig trenches, place wire entanglements, construct machine-gun emplacements, build pontoon bridges, and to construct roads. They must also be familiar with the methods of demolition, sapping and mining. Specialized training in lithography, zincography, surveying, mapping, photography, carpentry, blacksmithing, electricity and machinery are also given to those qualified for further training in any of these branches.

Engineers are called upon to perform such a wide range of work that practically every man with any technical training or mechanical ability can find a place in this organization. Every male citizen in the United States who is physically fit and between the ages of 18 and 21, or 31 and 40, is eligible to join the regiment by voluntarily enlisting.

Applicants for enlistment should write to the Commanding Officer, First Replacement Regiment Engineers, Room 107, Headquarters Building, Post of Washington Barracks, D. C., for an application form. If the blank shows the man to be eligible, an enlistment card is filled out and sent to the Recruiting Office nearest to the applicant's place of residence with instructions to enlist the man for service in this regiment. Transportation and meals will be furnished by the Recruiting Officer and the man will be instructed to report at the Post for duty.

It is important that applicants comply with these instructions closely, as otherwise it may be found impossible to effect a transfer to the organization after enlistment.

War Training for Electricians and Telephone Men: A war training course for electricians and telephone men needed for the United States Army has just been published by the Federal Board for Vocational Education. This course, it is planned, will be given to drafted men, enlisted and detailed on subsistence and pay to schools cooperating with the Federal Government in the preparation of mechanics and technicians for military service.

The course consists of 36 lectures and four class room, field and shop units on electric wiring, testing, motors and generators, and telephone work. The instruction book is known as Bulletin No. 9, and may be had free on application to the Federal Board for Vocational Education, Ouray Building, Washington, D. C. Similar bulletins for training enlisted men in various trades have been prepared by the board and will be announced upon publication.

GREETINGS FROM ITALIAN ENGINEERS

On March 4, 1918, the following message was received by President Rice of the American Institute of Electrical Engineers. "To President, American Institute Electrical Engineers, New York. The Associasione Elettrotecnica Italiana visiting wireless station, Rome, send greetings to the American Institute of Electrical Engineers, with full confidence of final victory for the Allies. Semenza, President."

President Rice replied to this message as follows: "Your greetings by

wireless just received. American electrical engineers are proud to be associated with those of Italy, the land of Volta and Marconi, in united service for civilization. We share your supreme confidence in the final and complete victory of our righteous cause."

PAST-SECTION MEETINGS

Chicago.—February 25, 1918, Western Society of Engineers. Subject: Electric Furnaces. Papers: (1) "Resistance-Type Furnaces of Large Capacity," by Thaddeus Bailey; (2) "Arc-Type Electric Furnaces," by John A. Seede. Attendance 221.

Cleveland.—January 21, 1918, Hotel Statler, Electrical League Club Rooms. Address by Mr. W. R. Hazlett on "Storage Battery Designing." Attendance 47.

February 18, 1918, Hotel Statler, Electrical League Club Rooms. Address by Mr. L. P. Crecelius on "The Design, Cost and Performance of the New Cedar Avenue Substation of the Cleveland Railway Company." Before the meeting the members met at the substation for an inspection trip. Attendance 55.

Denver.—February 16, 1918. Denver Athletic Club. Address by Mr. F. W. Hild on "American Electric Railways and the War." Attendance 38.

Detroit-Ann Arbor.—February 8, 1918, Detroit Board of Commerce. Address by Mr. F. R. Temple on "Telephone Engineering." Attendance 20.

Erie.—February 12, 1918, Board of Commerce Rooms. Paper: "Hydroelectric Developments," by R. C. Muir. Election of Officers as follows—chairman, Clayton P. Yoder; secretary-treasurer, Scott S. Hill; board of directors, Messrs. James Burke, A. Hunter Willis and Hermann Lemp. Attendance 116.

Ithaca.—January 18, 1918, Franklin Hall. Address by Mr. T. A. Worcester on "Modern Transmission Line Practise." Attendance 50.

February 22, 1918, Franklin Hall, Cornell University. Paper: "Electric Starters for Automobiles," by K. O. Wolcott. Attendance 52.

Los Angeles.—February 19, 1918, Walker Building. Paper: "Present Comparative Costs of Power to the Consumer in Southern California," by Clem A. Copeland. Attendance 25.

Lynn.—February 13, 1918, G. E. Hall. Address by Mr. W. R. Balch on "What the World War will do to Lynn." Attendance 347.

February 27, 1918, G. E. Hall. Illustrated lecture by Prof. Elihu Thomson on "Electric Welding." Attendance 280.

March 13, 1918, G. E. Hall. Paper: "Applications of Electric Furnaces," by G. Cramer. Attendance 310.

Milwaukee.—February 13, 1918, City Club. Illustrated addresses as follows: (1) "Cold Accumulators and Their Application to the Refrigerating Industry," by E. S. H. Baars; (2) "The Refrigerating Equipments in the U. S. Army Cantonments," by A. H. Luedcke. Joint meeting with the Milwaukee Engineers Society. Attendance 210.

March 13, 1918, City Club. Lecture by Prof. Cyril M. Jansky on "Science in War." Attendance 200.

Minnesota.—February 28, 1918, University of Minnesota. Paper: "Central Station Heating," by John R. Allen. Attendance 75.

Philadelphia.—January 28, 1918, Engineers' Club. Subject: "Specifications Covering the Construction at Crossings of Overhead Lines of Public Utilities." Speakers: Paul Spencer and G. E. Wendle. Attendance 85.

February 11, 1918, Engineers' Club. Paper: "Some of the Broader Aspects of Utility Engineering," by J. S. Francis. Attendance 105.

March 11, 1918, Engineers' Club. Paper: "Progress in the Use of Electricity on Board Ships and in Shipbuilding," by H. A. Hornor. Attendance 169.

Pittsburgh.—February 13, 1918, Chamber of Commerce Bldg. Paper:

"Electrical Equipment of Government Standardized Trucks," by C. E. Wilson. Attendance 210.

March 12, 1918, Chamber of Commerce. Paper: "Automatic Substations," by R. J. Wensley. Attendance 210.

Pittsfield.—February 16, 1918, Masonic Temple. Illustrated lecture by Mr. Augustus Post on "The Allies' Message to America." Attendance 700.

February 28, 1918, Hotel Wendell. Illustrated lecture by Mr. John B. Taylor on "The Phonograph; Experiments and Study with the Microscope." Attendance 110.

Portland.—February 5, 1918, Multnomah Hotel. Address by Dr. William Conger Morgan on "Chemistry and the War." Attendance 131.

Rochester.—January 25, 1918, Rochester Engineering Society Rooms. Paper: "The Entz Transmission as Applied to Automobiles," by Mr. Barnett. Attendance 30.

February 21, 1918, Rochester Engineering Society Rooms. Illustrated lecture on "The Electrification of Steam Railroads," by Mr. M. C. Turpin. Attendance 42.

St. Louis.—February 27, 1918, Engineers Club. Paper: "Some Applications of Electric Power to Mining," by K. A. Pauly. Attendance 45.

Schenectady.—February 20, 1918, Edison Club Hall. Address by Mr. P. W. Wilson, special correspondent of *London Daily News*, on "Britian at War." Attendance 224.

March 1, 1918, Edison Club Hall. Paper: "The Automobile Headlight Problem," by C. A. B. Halvorson. Attendance 225.

Seattle.—February 19, 1918, Arctic Building. Paper: "Alternating-Current Motors," by C. Kirk Hillman. Address by Mr. J. B. Fisken on Institute Activities. Attendance 45.

Spokane.—February 15, 1918, Assembly Rooms, W. W. P. Co. Bldg. Symposium on "Distribution" presented by Messrs. G. H. Hoppin, E. L. Blaine, F. L. Rohrbach, O. O. Coffman, J. G. Finley, L. J. Corbett, and G. S. Covey. Address by Mr. J. B. Fisken on "Retrospect of the Spokane Section." Attendance 43.

Toronto.—February 15, 1918, Engineers' Club. Lecture by Mr. C. R. Dooley on "Training Men for Industry." Attendance 55.

March 1, 1918, Engineers Club. Paper: "Commercial and Industrial Research," by R. P. Jackson. The paper was illustrated with lantern slides. Attendance 40.

Washington.—February 5, 1918, Rauscher's. Illustrated address by Dr. George Ellery Hale on "Science and the War." Attendance 160.

March 12, 1918, Cosmos Club Hall. Address by Mr. H. M. Hobart on "Engineering Progress in Great Britain." Captain Caldwell of the British Army gave a talk on "Rapid Engineering Progress brought about by the War." Attendance 90.

PAST BRANCH MEETINGS

Alabama Polytechnic Institute.—March 5, 1918, Engineering Auditorium. Address by Prof. Hill on "Some Developments in the Electrical Industry during 1917." Attendance 10.

University of Arkansas.—February 18, 1918, Engineering Hall. Four reel motion picture "From the Ore to the Finished Pipe," by courtesy of National Tube Company. Attendance 13.

March 4, 1918, Engineering Hall. Address by Mr. J. C. Moody on "Modern Artillery Practise." Attendance 14.

Armour Institute.—February 19, 1918, Engineering Rooms. Address by Mr. A. W. Rahn on "Manufacturing Principles." Joint meeting with Armour Civil Engineering Society. Attendance 37.

Carnegie Institute of Technology.—February 20, 1918, Machinery Hall. Paper: "Recent Developments in Switchboard Design," by J. M. Brown. Attendance 28.

Clarkson College of Technology.—February 20, 1918. Paper: "My

Experiences as a Constructing Engineer," by Professor Wilson. Attendance 19.

University of Idaho.—February 14, 1918. Illustrated lecture on "Illumination of the Home." Attendance 38.

February 20, 1918. Three reel motion picture entitled "The King of the Rails." Mr. W. H. Eller gave a descriptive talk of the pictures. Mr. W. H. Eller gave a descriptive talk of the pictures. Attendance 43.

Kansas State Agricultural College.—January 17, 1918, Denison Hall. Paper: "The Audion Detector," by F. L. Sahlman. Address on "The Fuel Situation," by Clifford Joss. Attendance 24.

February 14, 1918, Denison Hall. Papers: (1) "Manufacturing Engineering," by H. M. Duphorne; (2) The Edison Storage Battery," by M. Lucas; (3) "The Electrification of Railways as a War Measure," by J. K. Pike. Attendance 18.

Lehigh University.—February 21, 1918, Physical Laboratory. Papers: (1) "Important Aspects of the Motor Application Field," by C. E. Clewell; (2) "Welfare Work at the General Electric Company," by H. I. Moll. Attendance 50.

University of Maine.—February 13, 1918. Papers: (1) "Summer Work; Telephone Instruction," by D. M. Libby. (2) "Summer Work; Building Condensers, and Capacity Measurements," by W. J. Creamer, Jr. Attendance 30.

Massachusetts Institute of Technology.—February 19, 1918, Smith Hall. Lecture by Prof. William S. Franklin on "The Mechanical Analogs of Electrical Phenomena." Attendance 43.

University of Minnesota.—March 4, 1918, Engineering Auditorium. Paper: "Description of the Minneapolis General Electric Company's Plant," by Mr. Whiton. Attendance 26.

University of Missouri.—February 18, 1918, Y. M. C. A. Bldg. Paper: "A-C. Motors for Electric Railways," by Earl Grossbeck. Attendance 16.

March 4, 1918, Y. M. C. A. Bldg. Paper: "Methods of Illumination for Motion Pictures," by L. Grigsby. Attendance 16.

University of North Carolina.—March 6, 1918. Address by Prof. P. H. Daggett on "The War, the Engineer, and the Future." Attendance 11.

North Carolina College of Agricultural and Mechanical Arts.—February 4, 1918. Lecture by Mr. P. B. Fleming on "The Mercury Arcs and Vibrating Rectifiers." Attendance 15.

February 11, 1918. Lectures as follows: (1) "The Theory of Radio Communication," by B. B. Brown; (2) "Abbreviations and Symbols Used in Practical Operation of Wireless Codes." Attendance 15.

University of North Dakota.—February 25, 1918, Mechanical Arts Building. Illustrated lecture on "A-C. Generators and Synchronous Motors." Attendance 8.

March 14, 1918, Mechanic Arts Building. Illustrated lecture on "The Evolution of the Transformer." Election of officers as follows: president, E. L. Marsh; secretary, Emery Berry. Attendance 10.

Ohio Northern University.—February 12, 1918. Address by Mr. A. J. Ferlic on "Transmission Towers." Attendance 19.

February 20, 1918. Addresses as follows: (1) "Modern Physics," by Prof. F. L. Berger; (2) "High Voltage Insulators," by H. L. Rudolph. Attendance 25.

Ohio State University.—February 25, 1918, University Chapel. Illustrated address by Mr. M. C. Turpin on "The Electrification of Steam Railways." Attendance 105.

University of Oklahoma.—February 11, 1918, Engineering Building. Informal reports on the Senior Inspection Trip. Attendance 13.

March 12, 1918, Engineering Building Paper: "The Kenotron, and the Tungar Rectifier," by C. H. Whitwell. Attendance 10.

Oregon Agricultural College.—February 20, 1918. Address by Mr. J. E.

Heukle on "Practical Experiences in the Central Station." Attendance 23.

Purdue University.—February 12, 1918, Electrical Building. Paper: "Magnetos," by H. W. Asire. Attendance 46.

February 19, 1918, Electrical Building. Paper: "Electric Ship Propulsion," by Mr. Pugh. Attendance 38.

March 5, 1918, Electrical Building. Four reel film entitled "Edison the Benefactor," through courtesy of General Electric Company. Attendance 117.

Queen's University.—February 25, 1918, Engineering Building Library. Lecture by Prof. Henderson on "Canada's Coal Problem."

Rensselaer Polytechnic Institute.—February 13, 1918, Russel Sage Laboratory. Illustrated address by Mr. Lowe on the installations of the Doherty Company, especially in connection with their oil industry. Attendance 33.

University of Texas.—January 17, 1918. Motion picture "The Benefactor," through courtesy of General Electric Company. Attendance 365.

Agricultural and Mechanical College of Texas.—February 13, 1918. Motion picture entitled "The Manufacture of Curtis Steam Turbines." Attendance 168.

State College of Washington.—February 15, 1918. Address by Prof. O. L. Waller on "The Men You Live With" Attendance 16.

March 8, 1918, Mechanic Arts Building. Paper: "Rating of Steam and Electric Locomotives," by Prof. L. V. Edwards. Attendance 14.

University of Washington.—February 5, 1918, Forestry Hall. Lecture by Mr. F. K. Kirsten on "The Pencil as a Conveyor of Engineering Thought." Attendance 16.

March 5, 1918, Forestry Hall. Address by Mr. L. M. Moyer on "Oil Circuit Breakers." Attendance 11.

Yale University.—February 18, 1918. Paper: "Electric Meters," by R. C. Lanphier. Attendance 44.

March 8, 1918. Paper: "Nitrogen from the Air for Explosives," by E. Kilburn Scott. Attendance 125.

ASSOCIATES ELECTED, MARCH 8, 1918

ANDERSON, ADRIEN LOUIS, Electrical Engineer, Federal Telegraph Co., Palo Alto; res., Stanford University, Cal.

*ANDREWS, FRANCIS E., Assistant Inspector, Public Service Co.; res., 156 E. 25th St., Chicago Heights, Ill.

BAILEY, RAND STEPHEN, District Plant Engineer, New England Tel. & Tel. Co., Lowell; res., 448 Main St., Haverhill, Mass.

BAKER, MILTON PALMER, Electrical & Radio Engineer, Liberty Electric Corp.; res., 38 Sound View St., Port Chester, N. Y.

*BALYEAT, ROY H., Chief Electrician in charge, Naval Radio Station, Port Arthur, Texas.

BENDER, OSCAR GEORGE, Production Engineer, Transformer Dept., General Electric Company, Ft. Wayne, Ind.

BICKING, WILLIAM L., Switchman, Diamond State Telephone Co.; res., 812 N. Harrison St., Wilmington, Del.

*BLACKMAN, LEON S., Junior Tel. & Tel. Engineer, Interstate Commerce Commission, Bureau of Valuation, San Francisco, Cal.

*BOISSONNAULT, FRANK LESLIE, Testing Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

BOON, ELVIN E., Commercial Engineer, Industrial Dept., Mining Section, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

BOYAJIAN, ARAM, Electrical Engineer, General Electric Co.; res., 58 Hull Ave., Pittsfield, Mass.

*BRACKEN, JAMES L. F., Electrical Draughtsman, Van Nest Electric Locomotive Shops, New Haven R. R.; res., 15 Elliott St., New Haven, Conn.

BRALEY, HOWARD D., Electrical Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 7833 Bennett St., Pittsburgh, Pa.

BRESSLER, NORMAN J., Chief System Operator, Metropolitan Edison Co.; res., 167 W. Greenwich St., Reading, Pa.

BRITT, E. G., Electrical Construction Supt., Southwest General Electric Co., Dallas, Texas.

BRUECK, HAWORTH LYSANDER, Sales Engineer, Electric Appliance Co., Jackson, Miss.; res., 437 W. North St., Decatur, Ill.

BUEFFEL, BERNARD HENRY, Plant Dept., New York Telephone Co.; res., 426 E. 188th St., New York, N. Y.

*BUREAU, ERNEST A., Professor of Physics, State Manual Training Normal; res., 217 W. Adams, Pittsburgh, Kansas.

*BURGETT, LYNN SMITH, Electrical & Mechanical Inspector, The Panama Canal; res., 229 First St. N. E., Washington, D. C.

*CANAVACIOL, FRANK EMANUEL, Student, Brooklyn Polytechnic Institute, Brooklyn; res., 427 Amsterdam Ave., New York, N. Y.

CARPENTER, ROBERT B., Asst. Supt., Electrical Dept., Southern Public Utilities Co.; res., 1605 Pendelton St., Greenville, S. C.

CAVE, JOSEPH, Chief Electrician, Canadian Allis-Chalmers Co. Ltd.; res., 89 Edwin Ave., Toronto, Ontario, Can.

CHAPIN, SPRAGUE L., Electrician & Draftsman, Anaconda Copper Mining Co.; res., 2512 Central Ave., Great Falls, Mont.

COLBY, LLEWELLYN A., Inspection of Motors, General Electric Co.; res., 100 Tyler St., Pittsfield, Mass.

COLEMAN, HARRY CHARLES, Elec.Engr., Gen. Engg. Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1110 Center St., Wilkinsburg, Pa.

CONOVER, HIRAM J., Chief Electrical Operator, Buffalo General Electric Co.; res., 77 Eckert St., Buffalo, N. Y.

*CORWITH, HOWARD POST, Engineering Assistant to Vice-Pres., Western Union Telegraph Co., New York; res., 76 Smith St., Freeport, N. Y.

CUMMINGS, B. RAY, Expert Radio Aid, Radio Div., Bureau of Steam Engg.; res., 1926 Eye St. N. W., Washington, D. C.

DALRYMPLE, FRANK Y., Operator, Pennsylvania R. R., Stockton, N. J.

DARRAH, J. LESLIE, Manager, Western Territory, Mineral Point Public Service Co., Mineral Point, Wis.

*DAS NEVES, JOSE GALIANO, Student Apprentice Course, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

DEXTER, BROWNING DEWEY, Asst. Engr., California Railroad Comm., San Francisco; res., 2519 Ashby Ave., Berkeley, Cal.

*DIMMITT, CLARENCE ELMER, Testing Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 816 Ross Ave., Wilkinsburg, Pa.

*ELLIOTT, VERNE DONALD, Electrical Engineer, So. California Edison Co., Los Angeles; res., 21 Bowen Court, Pasadena, Cal.

EVANS, G. H., Senior Shift Engineer, Government Hydro-Electric Power Station, Waddamana, Tasmania.

FOX, ALFRED C., General Superintendent, General Utilities Corp., Exchange Bank Bldg.; res., 578 Grand Ave., St. Paul, Minn.

FREDERICK, LOUIS T., Research Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Braddock Road, Wilkinsburg, Pa.

FRYE, M. A., Engineering Dept., Western Union Telegraph Co., Chicago; res., 1518 Grove St., Evanston, Ill.

GARDNER, STERLING MARSHALL, Electrical Engineer, Bay Point Elec. Supply Co., Bay Point, Cal.

*GRASS, SAMUEL A., Draftsman, Station Constr. Dept., Philadelphia Electric Co.; res., 1545 N. 6th St., Philadelphia, Pa.

GREEN, C. E., President, Green Engineering & Construction Co., Richfield, Utah.

GREEN, IRVING WALTER, Telephone Engineer, New York Telephone Co., 195 Broadway, New York, N. Y.; res., 85 Clark St., Jersey City, N. J.

GRIFFITH, GEORGE LESLIE, Electrical Engineer (Chief), American X-Ray Equipment Co., Mt. Vernon; res., 2056 Davidson Ave., New York, N.Y.

GRIFFITH, HENRY FOSTER, Assistant Manager, Westinghouse Electric Export Co., E. Pittsburgh; res., 447 Locust St., Edgewood Park, Pittsburgh, Pa.

HALL, OWEN THATCHER, Supt., Electric Construction, American Railways, Philadelphia, Pa.; res., 672 Columbia Ave., Baltimore, Md.

HALSEY, EDWARD S., Consulting Engineer, The Robeson, Camden, N. J.

HANDLEY, HARRISON KENNETH, Distribution Engineer, Texas Construction Co.; res., 2717 LaClede Ave., Dallas, Texas.

HANSEN, VERNE, Asst. Gen. Foreman, Testing Dept., General Electric Co.; res., 28 Mynderse St., Schenectady, N. Y.

HENDERSON, WARREN E., Contractor, Western Electric Co.; res., Ortonville, Minn.

HERON, LOUIS MANN, Instructor, Electrical Construction, McKinley Manual Training School; res., 1440 R. St., N. W., Washington, D. C.

HESS, ERNEST E., Draftsman, Spang & Co., Younkins Building, S. Main St., Butler, Pa.

HESTON, WALTER C., Line Engineer, Portland Railway Light & Power Co.; res., 778 Glisan St., Portland, Ore.

HILYARD, EDGAR GREGG, Chief Switchman, Diamond State Telephone Co.; res., 313 W. 30th St., Wilmington, Del.

HOFFECKER, JOHN IRVING, Wire Chief, The Diamond State Telephone Co.; res., 220 W. 22nd St., Wilmington, Del.

*HOFFMAN, HAROLD COMY, Test Table Operator, Bell Tel. Co. of Pa., Wyoming; res., 440 Roxborough Ave., Philadelphia, Pa.

*HOLLZER, MARC, Electrical Expert Aide, U. S. Naval Constructor's Office, Union Iron Works; res., 372 Herman St., San Francisco, Cal.

HOLMES, GEORGE, Editorial Staff, *Electrical Experimenter*, New York; res., Hastings-on-Hudson, N. Y.

*HOOKER, CALVIN ANDREW, Engineering Salesman, Westinghouse Elec. & Mfg. Co.; res., 212 Collingwood Ave., Detroit, Mich.

*HOPPER, DAVID CLAUDE, 419 S. Broad St., Philadelphia Pa.

*HORST, ARTHUR CARL, Sales Engineer, Westinghouse Elec. & Mfg. Co.; res., 3625 California Ave., N. S., Pittsburgh, Pa.

HORTH, RAYMOND S., Toll Wire Chief, Mountain States Tel. & Tel. Co.; res., 376 5th Ave., Salt Lake City, Utah.

HUBBELL, LEROY SAMUEL, Switchboard Engineer, Pacific Tel. & Tel. Co.; res., 812 31st Ave., San Francisco, Cal.

HUTCHINGS, JAMES, JR., Switchman, Central Office, Diamond State Telephone Co.; res., 14 E. 44th St., Wilmington, Del.

INGHAM, FRANCIS E., Correspondent, Westinghouse Electric Export Co., E. Pittsburgh; res., 123 N. Negley Ave., Pittsburgh, Pa.

JOHNSON, THEOPHILUS, JR., Expert Radio Aid, Radio Div., Bureau of Steam Engg., Navy Dept.; res., 1926 Eye St. N. W., Washington, D. C.

*JONES, GEORGE RAY, Estimator & Asst. Elec. Engineer, Minneapolis Electric Equipment Co.; res., 1111 4th St., S. E., Minneapolis, Minn.

KEMLY, FRANK J., Electrical Designer, with T. E. Murray, 130 E. 15th St., New York, N. Y.; res., 416 8th St., West New York, N. J.

KLINGMAN, LOREN ELMER, Foreman, Transformer Testing Dept., General Electric Co.; res., 927 Organ Ave., Ft. Wayne, Ind.

KOVAC, PAUL, Electrical Draftsman, New York Edison Co., 130 E. 15th St.; res., 169 E. 82nd St., New York, N. Y.

LA FORGE, ALBION N., Electrical Designer, with T. E. Murray, 124 E. 15th St., New York; res., 1972 61st St., Brooklyn, N. Y.

LAMBERT, MYLES B., Asst. Manager, Railway Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

*LEHERHOFF, RAYMOND GODFREY, 308th Field Signal Battalion, 83rd Div. National Army; res., 475 Riddle Road, Cincinnati, Ohio.

LESNIEWSKI, WITHOLD, Electrical Engineer, Russian Electric Company, Dynamo Ltd., 17 Bolshaia Koniou-shennaia, Petrograd, Russia.

LEWIS, JAMES PORCHER, Operating Dept., Alabama Power Co., res., Apt. "D" Richmond Apts., Birmingham, Ala.

LOOS, EMIL, JR., Canadian Sales Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 214 Dewey Ave., Edgewood, Pittsburgh, Pa.

LYNCH, E. DENNIS, Railway Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 738 Hill Ave., Wilkinsburg, Pa.

*LYMAN, OLIVER BRIDGMAN, Testing Dept., General Electric Co.; res., 217 Seward Place, Schenectady, N. Y.

LYTLE, JOHN HOWRY, Manager, Accessories Dept., Standard Underground Cable Co.; res., 308 Breading Ave., Ben Avon, Pittsburgh, Pa.

MARIHUGH, J. H., Asst. Electrical Supt., West Virginia Pulp & Paper Co.; res., 105 So. Third St., Mechanicsville, N. Y.

McCOY, THOMAS FRANKLIN, Division Construction Engineer, Mountain States Tel. & Tel. Co., Helena, Mont.

McGALL, MILTON JAMES, Electrical Draftsman, with T. E. Murray, 130 E. 15th St., New York, N. Y.; res., 341 Gregory Ave., W. Orange, N. J.

*McMANIGAL, ROBERT D., General Engg. Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 5599 Baum Blvd., Pittsburgh, Pa.

METTLER, AUGUSTUS H., Load Dispatcher, Electrical Dept., Homestake Mining Co.; res., 220 Sawyer St., Lead, So. Dakota.

MOCK, PALMER SCOTT, Inspector, Substation Construction Work, Penn. Railroad Co.; res., 5902 Greene St., Germantown, Philadelphia, Pa.

MOORE, PERCY N., Foreman, Elec. Apparatus Drafting, General Electric Co.; res., 169 Elm St., Pittsfield, Mass.

MURDOCK, ALEXANDER, JR., Electrical Engineer, D. L. Taylor Co., Inc., 403 Finance Bldg., Philadelphia; res., 47 Lincoln Ave., Lansdowne, Pa.

NEEDHAM, OLLIE, General Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 7725 Brashear St., Pittsburgh, Pa.

NEVILLE, JOHN, Chief Operator, Winnipeg Electric Railway, Mill St. Substation; res., 406 Cathedral Ave., Winnipeg, Man., Canada.

NEWELL, MILTON M., Testing Dept., General Electric Co.; res., 817½ State St., Schenectady, N. Y.

*OWENS, RAYMOND WILLIAM, Designing Engineer, Industrial Engg. Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 305 West St., Wilkinsburg, Pa.

PACKARD, M. F., General Engg. Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 548 Mifflin Ave., Wilkinsburg, Pa.

PARKS, JOE BAXTER, Sales Engineer, Westinghouse Elec. & Mfg. Co., 1442 Widener Bldg.; res., 6113 Jefferson St., Philadelphia, Pa.

PATTON, PAUL HARSHAM, Division Engineer, Nebraska Telephone Co.; res., 3519 Cuming St., Omaha, Neb.

PELLEY, CYRIL GORDON, Student, Cornell University, Ithaca, N. Y.; res., Greeley, Colo.

*PLAPP, ELMER BRAUER, Central Station Steam Engineer, Duquesne Light Co.; res., 5138 Woodlawn Ave., Pittsburgh, Pa.

*REASNER, GROVER C., Telephone Engineer, Central Union Telephone Co.; res., 223 N. Summit St., Indianapolis, Ind.

REDHEAD, ROBERT C., Service Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 2112 Hampton St., Swissvale, Pa.

REID, WILLIAM EGLINTON, Electrical Draftsman, Electric Bond & Share Co., 71 Broadway; res., 217 E. 79th St., New York, N. Y.

RENFREW, JAMES MACGREGOR, Captain Ordnance, R. C., Picatinny Arsenal, Dover, N. J.

ROSE, CHARLES FREDRIC, Chief Electrician, Nevada Consolidated Copper Co. Mines, Ruth, Nevada.

SCHARNBERG, HERMAN B., Mechanical & Electrical Engineer, Haitian American Sugar Corp., 25 Broad St., New York, N. Y.; res., Port au Prince, Haiti.

SCHROEDER, ERNEST PETER, Sales Engineer, Westinghouse Electric Export Co., E. Pittsburgh; res., 510 North Ave., Wilkinsburg, Pa.

SCHWARTZ, WILLIAM HENRY, Service Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1826 Lowrie St., N. S., Pittsburgh, Pa.

SCRIBNER, GEORGE KLINE, Chief Engineer, Boonton Rubber Mfg. Co.; res., Reserve St., Boonton, N. J.

SHEWHART, WALTER ANDREW, Research Engineer, Western Electric Co., 463 West St., New York, N. Y.

SMITH, ARTHUR D., Supt., Empire Gas & Electric Co.; res., 14 James St., Auburn, N. Y.

SMITH, BENJAMIN H., Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., R. D. No. 1, Turtle Creek, Pa.

SMITH, FARQUHAR WELLS, Engineer, New England Power Co.; res., 32 Schussler Road, Worcester, Mass.

*SMITH, GEORGE SHERMAN, Foreman, Testing Dept., General Electric Co.; res., 912 McClyman St., Schenectady, N. Y.

SNIFFIN, E. H., Manager, Power Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

STEPHANUS, ARTHUR DUELTGEN, Sales Dept., Westinghouse Electric Export Co., E. Pittsburgh; res., 604 Hampton Ave., Wilkinsburg, Pa.

STOCKMANN, ERLING B., Inspector of Ballistics, Ordnance Dept., Remington Arms U. M. C. Co.; res., 80 Vine St., Bridgeport, Conn.

STRECKER, HARRY LOUIS, Testing Dept., Crocker-Wheeler Co., Ampere, N. J.; res., 539 W. 144th St., New York, N. Y.

SWAYNE, EDWARD WARREN, Efficiency Engg. & Plant Accounting Supervisor, Bell Tel. Co. of Pa., 1211 Arch St., Philadelphia, Pa.

TAPSCOTT, RALPH HENRY, Asst. Chief Electrical Engineer, New York Edison Co., 124 E. 15th St., New York; res., Garden City, N. Y.

TESTARD, PAUL, Engineer, Ferranti, Ltd., Hollinwood, Lancashire, England; 219 Rue St. Honoré, Paris, France.

THOMPSON, JOHN THEODORE, Proprietor, Light Company, Sheridan; res., 500 E. 20th St. N., Portland, Ore.

THORN, GEORGE MAXWELL, Engineer, Power Dept., Penn. Public Service Co.; res., 425 W. Pine St., Clearfield, Pa.

TRENT, HAROLD ERNEST, Electrical Engineer, (Design), Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Murraysville, Pa.

*TRUESDELL, SIDNEY A., Junior Engineer, Service Investigation, Commonwealth Edison Elec. Co., 72 W. Adams St., Chicago, Ill.

VETTER, NELSON JOHN, Electric Draftsman, Lake Torpedo Boat Co., Bridgeport; res., 31 Tilton St., New Haven, Conn.

VOGAN, FRANK CARROLL, Electrical Engineer, Ballinger & Perrott, 17th & Arch St., Philadelphia; res., Glenside, Pa.

VOHSING, FRANK JOHN, Correspondent, Service Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1415 Lang Ave., Pittsburgh, Pa.

*WAITE, RAYMOND A., Instructor in Aerial Observation, School of Military Aeronautics, Univ. of California, Berkeley, Cal.

WAITE, R. P., First Operator, Oneida Power Sta., Utah Power & Light Co.; res., Oneida Club House, Preston, Idaho.

WALBURN, FRANKLIN SAMUEL, Factory Foreman, General Electric Co.; res., 1227 Ewing St., Ft. Wayne, Ind.

*WALDSCHMIDT, ALBERT, Laboratory Assistant, Bureau of Standards, Washington, D. C.; res., 933 Hanover St., Baltimore, Md.

WARNER, W. H., Statistician & Distribution Engineer, New York & Queens Electric Light & Power Co., Long Island City, N. Y.

*WEBB, ROSCOE HESS, Manager, Government Sales Section, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 527 Holmes St., Wilkinsburg, Pa.

WEEKS, HARRY EBEN, Operator, Metropolitan Water & Sewer Board; res., Sanderson Place, Clinton, Mass.

WERDEN, RALPH L., Telephone Engineering, American Telephone & Telegraph Co., 195 Broadway, New York, N. Y.; res., 22 Cane St., Bogota, N. J.

WHIPPLE, CLYDE COLBURN, Instructor in Electrical Engineering & Physics, Pratt Institute, Brooklyn, N. Y.

*WHITING, DONALD FAIRFAX, Electrical Engineer, Research Design, Engg. Dept., Western Electric Co., 463 West St., New York, N. Y.

*WILLSON, ABNER R., Inspectoro cf Eletrica Equipment, Kansas City Railways Co., res., 2922 Campbell, Kansas City, Mo.

WING, ALBERT E., Transformer Engineering Dept., General Electric Co.; res., 54 Grove St., Pittsfield, Mass.

WOODCOCK, FLOYD W., Gen. Supt., Eastern Shore Gas & Electric Co. & Subsidiary Companies; res., 233 Camden Ave., Salisbury, Md.

WOOTEN, ELMAR A., Salesman, Westinghouse Elec. & Mfg. Co., 1205 Dime Bank Bldg.; res., 176 Allendale Ave., Detroit, Mich.

WOOTTON, THOMAS WILLCOX, 4th Shift Engineer-in-Charge, Hydro-Electric Power Station, Waddamanna, Tasmania, Australasia.

WRIGHT, FRANKLIN BRODHEAD, Distribution Inspector, Philadelphia Electric Co., Philadelphia; res., 107 E. Greenwood Ave., Lansdowne, Pa.

*YATES, CECIL CLARKE, Telephone Engineer, American Tel. & Tel. Co., New York, N. Y.; res., 57 Washington St., E. Orange, N. J.

YEAGER, EMIL S., Tester, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1122 Brabec St., N. S., Pittsburgh, Pa.

YERBURY, RICHARD F., Chief Clerk, The Okonite Co.; res., 21 Irving Place, Passaic, N. J.

YOUNG, FRANCIS LIONEL, Div. Constr. Engg. Dept., Mountain States Tel. & Tel. Co.; res., 3027 Bosler Place, Denver, Colo.

*ZOLLINGER, JAMES EDWARD, Assistant Instructor, Chicago Central Station Institute; res., 1419 N. Dearborn St., Chicago, Ill.

*Former enrolled students.

Total 144.

ASSOCIATES RE-ELECTED MARCH 8, 1918

DIBBLE, CLAUDE MCCONAHA, Electrical-Mechanical Draftsman, The Arnold Co., 105 S. LaSalle St., Chicago, Ill.

GUILFORD, CHARLES T., Gen. Engineer, Westinghouse Elec. & Mfg. Co.; res., 6411 Kentucky Ave., E. Pittsburgh, Pa.

MULLERGREN, ARTHUR LEONARD. Elec. & Mech. Engr., Secy. & Treas., Benham Engineering Co., Colcord Bldg., Oklahoma City, Okla.

PATTERSON, WILLIAM HART, Industrial Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 305 Hutchinson Ave., Edgewood, Pa.

SEABROCK, HENRY HAMILTON, District Manager, Westinghouse Elec. & Mfg. Co., 1442 Widener Bldg., Philadelphia, Pa.

STEPHENS, ARTHUR PORTER, Electrical Engineer, E. Pittsburgh; res., Floral Park, Wilkinsburg, Pa.

MEMBERS ELECTED MARCH 8, 1918

DIGBY, WILLIAM POLLARD, Consulting Engineer, 48 Westminster Palace Gardens, Victoria St., London, S. W. 1, Eng.

EGERTON, HENRY C., Telephone Engineer, Western Electric Co., New York; res., 63 Bard St., Passaic, N. J.

ELDRED, CALVIN POWELL, Assoc. Prof. & Acting Head of Elec. Engg. Dept., Georgia School of Technology; res., 250 W. Peachtree St., Atlanta, Ga.

GOULD, WILLIAM MATTHEW, Engineering Dept., American Tel. & Tel. Co., 195 Broadway, New York; res., 130 Effingham Place, Westfield, N. J.

GANSER, HERBERT HARLAN, Manager, Schuylkill Dist., Counties Gas & Elec. Co.; res., 1433 Powell St., Norristown, Pa.

*MILLS, GEORGE ARTHUR, Electrical Engineer, Winnipeg Electric Railway Co., Winnipeg, Manitoba, Canada.

REINICKER, NORMAN GRAVES, Asst. to Chief Engr., N. Y. Edison Co., 124 E. 15th St., res., 434 W. 120th St., New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER MARCH 8, 1918

ARMSTRONG, EDWARD R., Experimental Engineer, E. I. DuPont de Nemours & Co., Wilmington, Del.

BARTON, THEOPHILUS F., Electrical Engineer, General Electric Co., Schenectady, N. Y.

MANSON, RAY H., Chief Engineer, Stromberg-Carlson Telephone Mfg. Co., Rochester, N. Y.

MCGOVERN, MAURICE T., Power & Mining Engineering Dept., General Electric Co., Schenectady, N. Y.

MERRILL, FRANK W., President, Merrill Electric Mfg. Co., Chicago, Ill.

NIKONOW, JOHN P., Member of the Russian Commission for Inspection of Artillery Orders, Bridgeport, Conn.

SCHATTNER, ERNEST, Chairman, Electrical Apparatus Co. Ltd., Vauxhall Works, London, England.

SEALEY, PERCY T., Operating Engineer, Illinois Northern Utilities Co., Dixon, Ill.

SMITH, CARLETON W., Electrical Engineer, Honolulu Iron Works Co., New York, N. Y.

WAUGH, LESTER R., Assistant Engineer, Chile Copper Co., Chuquicamata, Chile.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings mentioned below, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

Recommended for transfer by the Board of Examiners March 4, 1918.

To Grade of Fellow

BURROWS, CHARLES W., Associate Physicist, Bureau of Standards, Washington, D. C.

HALL, DAVID, D-C. Section Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

RHODES, GEORGE I., Mechanical and Electrical Engineer, Ford, Bacon & Davis, New York, N. Y.

To Grade of Member

SCHERIL, HENRY, Designing Engineer, Crocker-Wheeler Co., Ampere, N. J.; Instructor in Electrical Engineering, Cooper Union, New York, N. Y.

Recommended for Transfer by the Board of Examiners March 18, 1918.

To Grade of Member

EDWARDS, IRVING W., 1st Lieut. Ordnance R. C., United States Army, Birmingham, Ala.

HULL, ARTHUR H., Electrical Engineer, Station Design, Hydroelectric Power Commission of Ontario, Toronto, Ont.

RICHARDS, WILLIAM E., Superintendent, Electric Dept., Toledo Railways & Light Co., Toledo, O.

WHITNEY, ROY F., General Manager and Treasurer, Peoples Gas & Electric Co., Oswego, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before April 30, 1918.

Alward, E. T., (Member), Montreal, Que.
Ambrose, F. B., Youngstown, Ohio
Andrae, G. H. J., E. Pittsburgh, Pa.
Atkinson, W. S., New York, N. Y.
Baldwin, J. C. B., Toronto, Ont.
Barager, C. A., Montevideo, Minn.
Beckwith, A., Los Angeles, Cal.
Bennett, M. H., Waterbury, Conn.
Berry, A. F., New York, N. Y.
Bevington, H. P., Cristobal, C. Z.
Bibb, E. K., Camden, N. J.
Boeck, C. F., New York, N. Y.
Boorzhinsky, N., New York, N. Y.
Bower, G. W., Camden, N. J.
Bradley, J. F., New York, N. Y.
Bradt, A. W., Hamilton, Ont.
Brooks, L., Erie, Pa.
Brumelle, H. E., N. Y.
Cartwright, K. C., Norfolk, Va.
Catching, W. R., Oakland, Cal.
Chesebro, H. I., New York, N. Y.
Cooley, T. R., Milwaukee, Wis.
Crawford, R. F., Lead, S. Dakota
Cuff, P. S., Schenectady, N. Y.
Curtis, A. S., New York, N. Y.
Dorschel, W. E., Curtis Bay, Mich.
Doyle, G. A., Philadelphia, Pa.
Dusenbery, H. S., San Francisco, Cal.
Dwyer, W. O'B., Pittsfield, Mass.
Eaton, G. O., Boston, Mass.
Emerson, C. W., Jr., New York, N. Y.
Emerson, J. E., Toronto, Ont.
Everett, O. S., Boston, Mass.
Farnsworth, J. P., Boston, Mass.
Frandsen, F., Seattle, Wash.
Freeman, W. C., Rochester, N. Y.
Frenz, H. J., E. Pittsburgh, Pa.
Galpin, W. D., Schenectady, N. Y.
Gillilau, P. M., Schenectady, N. Y.
Goodes, A. W., Dundas, Ont.
Gorry, E. W., New York, N. Y.
Grasett, C. S., Toronto, Ont.
Greene, E. W., (Member), Honolulu, Hawaii
Grove, R. B., New York, N. Y.
Haas, R. E., Jr., New York, N. Y.
Hailey, R. L., New York, N. Y.
Hanenkamp, G. W., New York, N. Y.
Harrison, F. L., Toronto, Ont.
Harvie, H., Toronto, Ont.
Heckman, C. L., Boston, Mass.
Hiett, H. L., Byllesby, Va.
Hiltz, G. S., New York, N. Y.
Horimura, H., Scotia, N. Y.
Houts, G. J., Chicago, Ill.
Hoy, G. A., Philadelphia, Pa.
Hubbert, W., Seattle, Wash.
Ives, J. N., Boston, Mass.
Jacobson, C., Le Grande, Wash.
Jacobson, O., Denver, Colo.
Jewett, J. M., Richmond, Va.
Joyce, H., New York, N. Y.
Kane, T. F., Seattle, Wash.
Kelley, S. O., Camden, N. J.
Kilpatrick, A. S., Boston, Mass.
Kimball, J. T., Madison, Wis.
Klenk, F. F., Baltimore, Md.
Knollmeyer, L. F., (Member), Pittsfield, Mass.
Krebs, A. V., Los Angeles, Cal.
Kroger, W. H., New York, N. Y.
Lamson, H. W., Boston, Mass.
Lang, J. G. V., (Member), New York, N. Y.
Larson, I. J., New York, N. Y.
Lawrence, B. F., Philadelphia, Pa.
Leacock, G. D. Y., Toronto, Ont.
Levy, S. J., Brooklyn, N. Y.
Lyle, G. H., Balboa Heights, C. Z.
Lynch, F. A., Gloucester, N. J.
Mace, A. E., Boston, Mass.
Macneill, H. T., Miraflores, C. Z.
Main, W. R., Burlington, N. J.
Martin, DeL., Seattle, Wash.
Mason, C. D., Oak Grove, Mich.
Massey, N. E., Camden, N. J.
Matson, J. J., Schenectady, N. Y.
McFarland, J. C., Detroit, Mich.
McKay, W., Philadelphia, Pa.
Meagher, C. F., Seattle, Wash.

Mieth, C. A., New York, N. Y.
Miller, E. C., Seattle, Wash.
Miller, H. R., Norfolk, Va.
Morris, E. V., Athens, Ohio
Motokawa, I., E. Pittsburgh, Pa.
Moxey, L. W., Jr., (Member), Philadelphia, Pa.
Mowry, H. W., Chicago, Ill.
Nagel, H. C., E. Pittsburgh, Pa.
Nichols, E. G., Cedar Rapids, Ia.
Nichols, G.B., (Member), Albany,N. Y.
O'Connell, W. T., Panama Canal, C. Z.
O'Donnell, E. C., New York, N. Y.
Olander, F. B., E. Pittsburgh, Pa.
O'Leary, J. W., Chicago, Ill.
Orth, S. A., Detroit, Mich.
Osborne, R. W., Hamilton, Ont.
Oswald, E. P. E., Highland, Mich.
Overpeck, J. H., E. Pittsburgh, Pa.
Oyama, M., New York, N. Y.
Phillippi, C. A. F., Reading, Pa.
Pigg, H. F., (Member), Mineville, N. Y.
Pritchard, J. F., Ardmore, Okla.
Probst, R. O., South Bend, Ind.
Quinan, G. E., Seattle, Wash.
Rademacher, W. H., Newark, N. J.
Re Qua, F. L., Milwaukee, Wis.
Ricker, C. W., Cambridge, Mass.
Roeser, E. A., Rochester, N. Y.
Rorer, W. N., New York, N. Y.
Rothenbuecher, A. H., Boston, Mass.
Rubel, W. G., Denver, Colo.
Sanborn, C. H., Boston, Mass.
Sanford, W. E., (Member), New York, N. Y.
Schmalz, O. K., Hyde Park, Mass.
Scott, R. C., Dundas, Ont.
Shaver, G. W., Ogden, Utah
Shaw, J. W., Hamilton, Ont.
Shay, J., New York, N. Y.
Shreve, J. N., (Member), New York, N. Y.
Silver, B. L., New York, N. Y.
Skinner, J. S., Jr., Cristobal, C. Z.
Small, W. G., Brockton, Mass.
Spangler, C. H., Reading, Pa.
Sperry, S. M., Reading, Pa.
Squires, H. W., Brooklyn, N. Y.
Starr, R. H., Toronto, Ont.
Stephens, H. O., Pittsfield, Mass.
Stevens, T. W., Seattle, Wash.
Street, W. A., Gatun, C. Z.
St. Aubin, A. E., Clarke City, P. Q.
Suzuki, M., Tokyo, Japan
Swartz, B. F., Erie, Pa.
Sylvester, W. V., Seattle, Wash.
Taylor, A. N., London, Ont.
Terpstra, D., Dorchester, Va.
Terry, F., Cristobal, C. Z.
Tiffany, E. L., Boston, Mass.
Todd, W. B., Wilmington, Del.
Tricker, W., Panama, C. Z.
Uribe, L. E., Panama City, R. P.
Urich, P. R., Erie, Pa.
Van Dyke, K. S., New York, N. Y.
Van Inwegen, J. W., New York, N. Y.,
Venkatrama, V., Nangavaram, India
Vernor, W. M., E. Pittsburgh, Pa.
Wang, W. T., Hanyang, China
Waterbury, G. F., (Member), New York, N. Y.
Wheeler, R. H., (Member), Nitro, W. Va.
Whitehead, T., E. Pittsburgh, Pa.
Wigton, W. B., Seattle, Wash.
Worden, R. J., Hamilton, Ont.
Wright, J. W., Philadelphia, Pa.
Total 159.

STUDENTS ENROLLED MARCH 8, 1918

9483 Peters, O. F., Cooper Union
9484 Lopes, D. F., Ohio No. Univ.
9485 Mills, R., Ga. School of Tech.
9486 Apostolon, J.,Worcester Poly.Inst.
9487 Snider, E. B., Ohio No. Univ.
9488 Haruun, W. B., Poly. Tech. Inst. of Brooklyn
9489 Millard,A.M.,WorcesterPoly.Inst.
9490 Whitney, R. S., Univ. of Cólo.
9491 Beville, R. M., Virginia Poly. Inst.
9492 West, J.W.,Jr., Virginia Poly.Inst.
9493 Pritchard,C.H.,VirginiaPoly. Inst.
9494 Blaisdell, C. E., Wentworth Inst.
9495 Nottingham, W. F., School of Engg. of Milwaukee
9496 Thompson, M. F., N. Y. Elec.Sch.
9497 Seybold, L. F., Univ. of Wisconsin
9498 Tenney, E. V., Univ. of California
9499 Rohr, C. S., Univ of California
9500 Sweeney, W. M., Wentworth Inst.
9501 Davis, D. D., Univ. of California
9502 McMahon, A. E., Univ. of California
9503 Schmidt,C.W., Univ. of Wisconsin

9504 Derby, R. W., Wentworth Inst.
9505 Donohue, G. B., Marquette Univ.
9506 Phillips, E. W., Marquette Univ.
9507 Plumpton, A. G., Toronto Technical School
9508 Frampton, A. H., Toronto Technical School
9509 Roden, H. D., Virginia Poly. Tech. Inst.
9510 Frith, H. H., Virginia Poly. Tech. Inst.
9511 Berg, R. E., Lewis Inst.
9512 Bogen, D., Cooper Union
9513 Fong, G. H., Univ. of Michigan
9514 Fielding, D. W., Univ. of Texas
9515 Carpenter, L. G., Univ. of Texas
9516 Seaholm, W. E., Univ. of Texas
9517 Guse, C. E., State Coll. of Wash.
9518 Fukushima, F., Colorado Coll.
9519 Cole, D. I., Missouri State Univ.
9520 Gilt, C. M., Union Coll.
9521 Loewenthal, G. G., Univ. of Neb.
9522 Marshall, D. E., Univ. of Minn.
9523 Trull, F. G., Toronto Technical Sch.
9524 McCarter, H. A., Los Angeles Poly High School

Total 42.

OBITUARY

EDWARD W. STEVENSON, a cable specialist, was lost in the Florizel disaster. Mr. Stevenson has been supplying the British government since the war began with insulated wire and cable, and storage batteries and it was while on a trip in connection with this business that he lost his life. Through this death the electrical industry lost one of its pioneers. From 1880 to 1886 Mr. Stevenson was in the employ of the Telegraph Construction and Maintenance Company of London and for two years thereafter with the Commercial Cable Company. In 1889 he took charge of the Brush Electric Illuminating Company of New York. Later he was connected with the Okonite Company and the Hazard Manufacturing Company. In 1913 he became sales agent for Smith and Nicolls, manufacturers of wires. Mr. Stevenson became an Associate of the A.I.E.E. in 1903 and was advanced to the grade of Member in 1912.

PERSONAL

W. G. GORDON has resigned from the Canadian General Electric Company, with whom he has held the position of Transportation Engineer for over four years, and is entering into partnership with Theo. Malm in the Railway and Power Engineering Corporation, and in Malm, Gordon & Company, engineers. Mr. Gordon is an engineer of very wide experience in connection with city, interurban and trunk line electrification in this and foreign countries.

GEORGE F. SEVER formerly Professor of Electrical Engineering and Acting-Dean of the Faculty of Applied Science at Columbia University and for over twelve years Consulting Electrical Engineer for the Department of Water Supply, Gas & Electricity for the City of New York has been commissioned a Major in the Engineer Officers' Reserve Corps with headquarters in Washington, D. C. He has closed his engineering office in New York.

ACCESSIONS TO THE UNITED ENGINEERING SOCIETY LIBRARY

(From February 1, 1918, to March 1, 1918.)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made. These are taken either from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

A SHORT HISTORY OF SCIENCE.

By W. T. Sedgwick and H. W. Tyler. N. Y., The Macmillan Company, 1917. 15+474 pp., 9 x 6 in. cloth, $2.50.

The present work aims to furnish the student and the general reader with a concise account of the origin of that scientific knowledge and that scientific method which have come to have so important a share in shaping the conditions and directing the activities of human life. It is based on a lecture course given by the authors to undergraduate classes in the Massachusetts Institute of Technology for the purpose of furnishing a broad general perspective of the evolution of science, and of the relations of the sciences to each other and to the general progress of civilization.

AUTOMOBILE STARTING, LIGHTING AND IGNITION.

A Complete Exposition Explaining all Forms of Electrical Ignition Systems Used with Internal Combustion Engines of all Types, also Including a Comprehensive Series of Instructions Pertaining to Starting and Lighting Systems of Automobiles. By Victor W. Pagé. 4th ed., rev. N. Y., The Norman W. Henley Publishing Co., 1918. 519 pp., 298 illus., 8x5 in., flexible cloth, $1.50.

Intended for owners, operators and mechanics. Descriptions are non-mathematical but detailed. A chapter is devoted to the miscellaneous electrical devices used on automobiles.

AVIATION ENGINES.

Design, Construction, Operation and Repair. A Complete, Practical Treatise Outlining Clearly the Elements of Internal Combustion Engineering with Special Reference to the Design, Construction, Operation and Repair of Airplane Power Plants; also the Auxiliary Engine Systems, such as Lubrication, Carburetion, Ignition and Cooling. It Includes Complete Instructions for Engine Repairing and Systematic Location of Troubles, Tool Equipment and Use of Tools, also Outlines the Latest Mechanical Processes. By Victor W. Pagé. N. Y., The Norman W. Henley Publishing Co., 1918. 589 pp., 253 illus., 9x6 in., cloth, $3.

A text-book prepared for instruction purposes especially for students preparing for service, as aviators or aviation mechanics in the Aviation Section, Signal Corps. The author is Assistant Engineering Officer in the Signal Corps Aviation School.

CENTRAL STATIONS.

By Terrell Croft. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co. Ltd., 1917. 10+332 pp., 306 illus., 8x6 in., cloth, $2.50.

A description of current practise in the generation, transmission and distribution of electrical energy, in a form adapted to readers of modest mathematical attainments. Contents: Distribution-System Nomenclature; Distribution Loss and Distribution Loss Factors; Maximum Demand and Demand Factors; Diversity and Diversity Factors; Load Factor, Plant Factor and Connected-Load Factor; Load Graphs and Their Significance; General Principles of Current Design; Calculation and Design of Direct-current Circuits; Calculation and Design of Alternating current Circuits; Transmission and Distribution of Electrical Energy; Lighting Protection Apparatus; Automatic Voltage Regulators Switchboards and Switchgear; Characteristics of Electric Generating Stations; Adaptability of Steam Internal Combustion Engine and Hydraulic Prime Movers; Steam Electrical-Energy-Generating Stations; Internal Combustion Engine Stations; Hydroelectric Stations.

CONTINUOUS-CURRENT MOTORS AND CONTROL APPARATUS.

A Practical Book for all Classes of Technical Readers. By W. Perren Maycock. N. Y. and Lond., Whittaker & Co., 1917. 16+331 pp., 150 illus., 8x5 in., cloth, $2.25 (gift of The Macmillan Co.).

Discusses the kinds of apparatus and motors in use, their connections, actions, testing and applications. Does not treat of design nor manufacture. Intended for those interested in installing and operating continuous-current motors.

DESCRIPTIVE GEOMETRY.

By Ervin Kenison and Harry Cyrus Bradley. N. Y., The Macmillan Com-

pany, 1917. 10+287 pp., 332 illus., 8x5 in., cloth, $2.

A college text-book, representing the instruction given at the Massachusetts Institute of Technology. The point of view is that of the draftsmen and the text is designed to train him to see clearly the conditions of a drawing in space.

DISTRICT HEATING.

A Brief Exposition of the Development of District Heating and its Position among Public Utilities. By S. Morgan Bushnell and Fred. B. Orr. N. Y., Heating and Ventilating Magazine Co., 1915. 290 pp., 82 illus., 1 por., 9x6 in., cloth, $3.

It has been the endeavor of the authors of this book to take up in a brief manner the development of the art of District Heating, as far as possible, from a non-technical standpoint, in order that those who have not had experience with this subject might obtain a general knowledge of District Heating and its relation to other public utilities. As a rule the discussion of the more involved technical points has been avoided, the reader being referred to standard text-books and other engineering literature which take up these subjects in detail.

The object of the book is not only to impart a general knowledge of District Heating to those who wish to study the subject, but also to promote the interests of District Heating companies. For this purpose various points on economical operation are suggested, as illustrated in the methods practised by companies which have made a success in this line of work. Comparative data are presented indicating the prices that can reasonably be charged for heating service. Contents: Origin and Development of District Heating; Selling of Heat; Heat Distribution Systems; Metering; District-Heating Stations; Methods of Estimating Heating Requirements in Buildings; Estimating Miscellaneous Steam Requirements in Buildings; Relation Between Heat Load and Electric Load in Buildings; The Use of Heating Data in Making Estimates on the Comparative Costs of Isolated Plant and Central-Station Service; Relation Between Central-Station Heating and Central-Station Lighting and Power.

DRYING CLAY WARES.

By Ellis Lovejoy, E.M. Indianapolis, T. A. Randall & Co., (copyright 1916). 166 pp., 86 illus., 9x6 in., cloth, $2.

As the existing treatises on heating, ventilation and drying do not contain adequate data applicable to the drying of clay wares, the author has selected the existing information of use in this work, and has modified it to suit the conditions met. Appeared first as a series of articles in the Clay-Worker.

ELEMENTS OF PLUMBING.

By Samuel Edward Dibble. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1918. 170 pp., 83 illus., 7x5 in., cloth, $1.50.

A text-book for beginners. Describes in minute detail the various methods used by plumbers, the tools and the standard forms of fixtures. Water supply to buildings, the removal of waste waters, and gas fitting are considered. Plumbing codes are given.

ENZYMES AND THEIR APPLICATIONS.

By Dr. Jean Effront. English translation by Samuel C. Prescott. N. Y., John Wiley & Sons; Lond., Chapman & Hall, Ltd., (copyright 1902). 11+332 pp., 9x6 in., cloth, $3.

Treats of the enzymes of carbohydrates and the oxidases. Gives particular attention to the theoretical questions involved in their action, but also discusses their industrial applications. Bibliographies are appended to each chapter.

FINDING AND STOPPING WASTE IN MODERN BOILER ROOMS.

Vol. 2. A Reference Manual to Aid the Owner, Manager and Boiler Room Operator in Securing and Maintaining Plant Economy. Phila., Harrison Safety Boiler Works, 1918. 274 pp., 120 illus., 7x5 in., lin, $1.

A handbook of practical information, compiled from the best authorities available. A convenient reference manual on boiler room practise. Contents: Fuels; Combustion; Heat Absorption; Boiler Efficiency and Boiler Testing; Boiler Plant Proportioning and Management; Cochrane Meters.

FRENCH FORESTS AND FORESTRY.

Tunisia, Algeria, Corsica with a Translation of the Algerian Code of 1903. By Theodore S. Woolsey, Jr. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 15+238 pp., 20 illus., 9x6 in., cloth, $2.50.

This work embodies the results of a study of the more important phases of forest practise in the French Colonies mentioned, with the aim of presenting the essentials of method which may be applied directly in the United States. Generalizations and comparisons between French and American methods have been largely omitted; the idea has been, instead, to describe the methods used and the results obtained in countries where many of the conditions approximate those met by American foresters.

KINEMATICS OF MACHINERY.

A Text-book on Mechanisms and their Properties with Many Practical Applications for Engineers and for Students in Technical Schools. By Arthur Warner Klein. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1917. 15+227 pp., 118 illus., 7 diagrams, 9x6 in., cloth, $2.50.

This treatise occupies itself with the equivalence displacement, velocities and accelerations of mechanisms and gives the necessary preliminaries in the way of auxiliary constructions and theorems with applications to many practical problems. These are solved by relatively simple graphical methods.

MEASUREMENT OF GAS BY ORIFICE METER.

By Henry P. Westcott. Erie, Metric Metal Works, 1918. 408 pp., 35 illus., tab., 8x5 in., cloth, $3.50.

While there have been many circulars and papers written on the subject of the orifice meter and orifice measurement, no attempt has been made to collect and preserve this data in book form, and it is the intention of the author to fill this need and, in addition, to add a full set of pressure extensions so necessary in figuring gage charts.

METER RATES FOR WATER WORKS.

By Allen Hazen. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1918. 217 pp., 21 illus., 9x6 in., cloth, $2.25.

This book deals with the problem of distributing the burden of supporting a water-works system among those who use the water, in a just and equitable manner. It also deals with the technic of handling statistics that must be used, of making the required computations and of estimating the revenue that will be produced by a given set of rates.

The volume is based on the author's service as Chairman of the Committee on Water Rates of the New England Water Works Association and his experience in establishing water rates in various water-works systems.

MODEL AEROPLANES AND THEIR ENGINES.

A Practical Book for Beginners. By George A. Cavanagh. Drawings by Harry G. Schultz with an introduction by Henry Woodhouse. N. Y., Moffat Yard & Company, 1917. 152 pp., 20 illus., 19 pl., 8x5 in., cloth, $1.

This work includes both models launched by hand and those driven by compressed air, gasoline or steam. Detailed directions for the construction of several types are given.

NOTES ON MILITARY EXPLOSIVES.

By Erasmus Weaver. 4th ed. rev. & enl. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 382 pp., 9x6 in., cloth, $3.25.

The present edition has been thoroughly revised and brought up to date by including the changes in the manufacture, use, storage and transportation of military explosives which have been developed between 1912 and 1916. Contents: Principles of Chemistry; Substances Used in the Manufacture of Explosives; General Remarks on Explosives; Progressive Explosives; Detonating Explosives; Exploders; Service Tests of Explosives; Storage of Explosives; Handling High Explosives; Demolitions.

OPTIC PROJECTION.

Principles, Installation and Use of the Magic Lantern, Projection Microscope, Reflecting Lantern, Moving Picture Machine. By Simon Henry Gage and Henry Phelps Gage. Ithaca, Comstock Publishing Co., 1914. 731 pp., 413 illus., 9x6 in., cloth, $3.

The aim of the authors has been to explain the underlying principles of optic projection and to give such simple, explicit directions that any intelligent person can succeed in all the fields of the art.

Contains appendixes giving a brief historical summary, a list of manufacturers and a bibliography.

POWER WIRING DIAGRAMS.

A Handbook of Connection Diagrams of Control and Protective Systems for Industrial Plants. By A. T. Dover. N. Y. and Lond., Whittaker & Co., 1917. 15+208 pp., 254 illus., 7x4 in., cloth, $2.25. (Gift of the Macmillan Co.)

A pocketbook of detail diagrams, drawn to represent the actual control apparatus to which they refer, instead of being merely ideal. The apparatus described is that used in Great Britain.

STATISTICS.

By William B. Bailey and John Cummings. Chic., A. C. McClurg & Co., 1917. 153 pp., 7x4 in., cloth, 60 cts.

An elementary work for those who need an acquaintance with the fundamentals of the subject. Mathematical formulas have been avoided when possible. A bibliography of works in English is included. Contents: Importance of Statistics; The Field of Study; Gathering the Raw Material; Editing Schedules; Tabulation;

Ratios; Averages; Graphic Representation; Correlation; Bibliography.

TESTING FOR THE FLOTATION PROCESS. By A. W. Fahrenwald. N. Y., John Wiley & Sons, Inc.; Londs., Chapman & Hall Ltd., 1917. 173 pp., 34 illus., 7x4 in., leather, $1.50.

Written to present the various theories of flotation and to furnish the information necessary to conduct intelligent tests for the flotation process. Contents: Concentration by Flotation; Classification of the Flotation Process; The Theory of Flotation; The Flotation of Oxidized Ores; Oil and other Reagents in Flotation; Tests; Cost of Flotation; Formulas and Tables.

THE ALDRICH MARINE DIRECTORY. Containing (A) List of Concerns which Build and Repair Vessels, (B) List of Steamship, Steamboat and other Vessel Owners Using the American Flag. N. Y., Aldrich Publishing Co., 1918. 220 pp., 8x4 in., flexible cloth, $5.

The lists are arranged geographically. The location, officers, kind and maximum size of vessels built are given for each shipyard. The list of owners gives the location, officers and the names tonnage and service of the vessels.

THE PRINCIPLES OF ECONOMIC GEOLOGY.

By William Harvey Emmons. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1918. 18+606 pp., 210 illus., 9x6 in., cloth, $4.

An attempt to present as briefly as practicable to advanced students of geology, a perspective of the science of metalliferous and nonmetalliferous deposits, excluding mineral fuels. Numerous bibliographies on special topics are included.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

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Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number in dicated in each case, and mailed to Institute headquarters.

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V-341. Wanted: Mechanical draftsman (exempt from draft) with knowledge of electrical engineering and mechanical refrigeration.

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V-348. Patent Attorney needed in the Patent Department of the Western Electric Company. Must be technically educated and experienced in patent matters. Apply by letter describing education and experience to J. G. Roberts, Attorney, Western Electric Company, 463 West Street, New York, N. Y.

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SERVICES AVAILABLE

925. Graduate in electrical engineering having had one and a half years' experience in the design and development of electro-mechanical devices, three years of efficiency engineering as applied to operating with respect to utilization of man-power to meet varying traffic conditions, manufacturing, installation and maintenance problems, offers his services.

926. Young man, 1917 electrical graduate, wishes position offering opportunity. Test and shop experience with one of the larger electrical manufacturers, now in the commercial department. Totally exempt from military service.

927. Electrical engineer, has proven technical and business ability, well posted on efficient plant methods, and is accustomed to responsibility. Experienced in telephone engineering, heat, light and power engineering. Transmission and construction for both classes of the above service, reports, etc. Will be available on reasonable notice. American, married.

928. Electrical engineer, technical graduate, in deferred draft class, age 28; eight years' experience in central station work and illuminating engineering, desires position with power company in West. Several years with one of largest central stations in the country. Familiar with best practise in overhead distribution. Married. Salary about $2,000.

929. Professor of electrical engineer, with both practical and teaching experience, is available in June or September as department head, or other position of responsibility. Now employed on the Pacific coast, but other locations will be considered. Minimum salary $2500.

930. University graduate in electrical engineering 1916, with eighteen months' experience on test floor of large company manufacturing electrical apparatus, desires position on construction work or with operating or manufacturing company. Now employed. Available on two weeks notice.

931. Wanted: Post as assistant professor in electrical engineering. Teaching and engineering experience both here and abroad. Could take work in engineering mathematics if desired. Available now.

932. Professorship of mechanical engineering desired by electrical gradu-

ate of well known technical college. Four years in college positions of responsibility in mechanical laboratory and lecture. Three years practical engineering, New York and West. Exceptionally experienced in central station practise and design, both electrical and mechanical. Present teaching salary $1600.

933. Electrical engineer, technical graduate, good mechanic, long experience in motors, switchboards, installation work and testing. Several years in charge of electrical department; can do designing and developing of ideas; good on experimental work. Understand steam engines and boilers. Competent to take charge of electrical department, assembling or winding, or power plant. Age 33. Salary about $35 per week.

934. Electrical engineer, 30 years of age, single, with r[illegible] technical and scientific training in telephone, high-frequency and electrochemical work, as well as in general electrical engineering. Six year's experience in development, design and research work with leading electrical companies of the world. Exempt from draft. Unqualified references to ability and loyalty.

935. Electrical and mechanical engineer with three years practical shop and testing work and six years successful teaching in large universities, with an A No. 1 record and best references, desires place where ability and originality is wanted. At present employed. Would accept college or commercial position paying not less than $2500 per year. Married.

936. Assistant professor of electrical engineering in midwestern state university. Good experience in both teaching and practical work. Age 33. Member of engineering societies. Desire to assume greater responsibilities and command larger opportunities. Present associations are excellent, limitations of present position only reason for change. Minimum $2500.

937. Progressive engineer, business and technical insight, aptitude for management problems, accustomed to responsibility, not a detailer, open for position in executive department. Electrical and mechanical university education. Experience principally steam equipment, designing, superintending construction, tests, accounting, contracting, office management, technical journalism, editing publicity matter. Versatile, successful. Age 35. Present location Philadelphia.

938. Electrical engineer, 32, university graduate (1910) with a technical training of high order and eight years broad practical experience in Europe and U. S.; able to adapt himself to variety of research, developing and designing work. Received a special testing training. Salary $2100-$2400.

939. Experienced in the management of plants operating Diesel oil engines, ice machinery, steam turbines and railway equipment. Present position electrical engineer for light and traction company. Minimum salary $3000.

940. Electrical engineer, technical training, ten years experience, chief draftsman on power station and substation design, underground transmission, construction and operation, distribution, testing and trouble location, electrolysis, estimating. Railway, light and power experience. Subscriber to Alex. Hamilton course. Desire permanent position, with opportunity for advancement.

941. Electrical engineer, technical graduate, 1904, age 35, married. Charge over ten years electrical work one largest Navy Yards Atlantic Coast. Experienced all phases shipyard work, including power plant, radio, storage battery engineering, machine tool applications, shop layouts, shipboard installations, directing large number men. Permanent position only considered. Salary not less $4000.

942. Electrical engineering graduate, Assoc. A. I. E. E., age 27, with three years' experience in construction, maintenance and operation of electrical equipment. Desires to locate with concern that offers advancement. Location in South America preferred.

943. Electrical engineer, power and industrial, technical graduate, age 36, married. Has had thirteen years' experience in industrial sales, motor applications, and general industrial engineering. For past eight years has been electrical engineer for one of the largest industrial plants in New York. Salary expected $4,800. Available upon thirty days notice.

944. Head of department of electricity and telephony at a well-known correspondence school desires position as assistant professor of electrical engineering, physics or mechanical engineering. Technical graduate 1910, degree M.E., four years' practical experience. In present position four years. Age 33, married. Available after June 1. Minimum salary $1800.

945. Open for position at $175 per month. Married, Protestant, age 27. Experienced and especially qualified in remote control, railway signaling, electric elevators, duct line construction, electrical (low-tension) distribution, care, operation and maintenance of D-C. and A-C. motors, generators and their appurtenances, engines, pumps, etc. Could take charge of armature winding shop.

946. Electrical engineer, technical graduate, 42, married, twelve years' experience in operation, maintenance and installation of steam and electrical machinery. At present in charge of construction of power plant. Will be available in April.

947. Married man, 31 years of age, class 4A of draft, desires position of responsibility, preferably in production or sales engineering department of reputable manufacturing company. Experience: One year engineering department of Western Electric Company and nine years in active charge of mechanical and electrical engineering students of prominent technical school of New York City.

948. Electrical engineer, technical graduate, experienced in power transmission, also central station distribution, both A.C. and D.C. desires position leading to an executive capacity. Available within one month. Age 32, married. Salary $3,000.

949. Technical graduate, electrical and mechanical engineer, twelve years' experience railway electrification, central power station, power plant and transmission line construction, desires position as electrical engineer or superintendent of electrical construction. Salary $3,000. Can give good references Present employed in railway electrification. Reason for change present locality undesirable.

950. Electrical and mechanical engineer, eight years' experience, powerhouse practice, designer of electromechanical devices, with original ideas; former chief draftsman of the Marconi Wireless Company; married, age 33.

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Lecture before the 6th Midwinter Convention of the American Institute of Electrical Engineers, New York, February 15, 1918.

SOME APPLICATIONS OF ELECTROMAGNETIC THEORY TO MATTER

BY ALBERT C. CREHORE

LAST year you were privileged to listen to an account of recent experimental observations in connection with atomic phenomena, I may say some of the fundamental facts of the physical world, coupled with an account of the way some of these facts are now generally interpreted in terms of "Radiation and Atomic Structure." The interpretation was principally in terms of the current Rutherford-Bohr theory of the atom.

It is the interpretation of physical observations that has engaged the speaker's attention for several years, and it has seemed to your committee that the time is ripe to present to you certain conclusions that have resulted. It goes without saying that no theory has ever yet been proposed that enables us to account for all the facts of observation by steps of logical deduction from certain assumed premises. Nevertheless, there is every reason why this high ideal should ever be kept before us. Unless we aim higher than we expect to attain, we will not accomplish so much as we expect.

I would not have you understand from this that no real progress toward the desired goal has been made. On the contrary, I believe it to be very great. How can we estimate the progress that has been made? Throughout the history of science we have seen one theory giving place to another sometimes in rapid succession. This has had a very depressing effect upon a certain class of people, who do not comprehend the real trend of it. I would impress upon you that this is one of the chief earmarks of progress. We cannot attain the realization of the ultimate goal at once, and, therefore, the only way to approach it is by a series of successive approximations. Each nearer approach involves of necessity some changes in preceding ideas.

It even seems probable that the fundamental hypothesis of atomic structure as composed of electrons, positive and negative, is entirely correct, and that the reason why we are not yet able

to account for more of the observed phenomena is because we have not discovered the proper processes to follow in reasoning from the simple to the complex. I suspect that this is the truth of the matter, and, when you comprehend more fully the complexities of most of the processes involved, you will experience no difficulty in agreeing with me.

The discovery of the electron and the isolation of it, so that its properties might be measured, marked a new era in our conception of matter. The fact that each electron always carries an electrical charge of the same amount is most significant. It has led by natural steps to the present electrical theory of matter. It was also most natural to begin to apply to these electrons, as representing electrical charges, the electromagnetic theory that is known to apply to other electrical charges, a theory that had been developed by a generation of men long before the electron was known, as the chief exponent of which the name of Maxwell stands preeminent. This was done, of course, but it was soon found that the existing form of electromagnetic theory was inadequate to cope with single isolated charges moving with considerable velocities through space.

Electromagnetic theory itself, therefore, became the object of much more careful study. The result has been that we have witnessed, even in our day, a gradual evolution of electromagnetic theory. Maxwell would hardly recognize the form in which electromagnetic equations are expressed today. The new thing that has been introduced into the theory is the conception that the effects of a charge moving through the ether are propagated out in all directions from it with a velocity which is characteristic of the ether, the same velocity as that of light. This introduces important differences into the equations, sometimes referred to as "retarded potentials."

Some progress was made by the use of this theory in interpreting atomic phenomena, but there were certain observations, particularly connected with radiation from gases, that simply refused to be brought into line in any way that could be conceived. On the strength of this Max Planck proposed what is now known as his "quantum theory." It stands today as one of the boldest proposals ever suggested in physics. He originally arrived at the theory through a consideration of the radiation of energy from gases, but it has since been shown to have a very general application in all atomic phenomena. The boldness of his proposal may be seen from the following. Finding that

electromagnetic theory was inadequate, as he conceived of it, he proposed to lay it aside and not use it. He then gave reasons for his proposal that, whenever energy is radiated anywhere from matter, the energy is transferred in units, or in quanta, so that the total energy transferred is some integral multiple of a fixed minimum of energy, the quantum.

Let it suffice to say that the application of Planck's quantum theory to radiation straightened out the difficulty immediately. Perhaps it would be better to say transferred the difficulty from one place to another, for difficulty there is and will be until the fundamental cause of the necessity for units or quanta of energy is comprehended. However, progress by the use of this new idea was very marked in every direction as regards atomic phenomena, The value of the unit or quantum of energy has now been experimentally determined. It is excessively small, but, when a quantity can be measured at all, its existence is not questioned. Its existence is now regarded as experimentally established.

The present trend of physicists is to generalize this idea, and to say that energy is essentially of an atomic nature, being composed of units in the same way as matter is so composed. This generalization implies that no flow of energy ever takes place that does not go in exact multiples of this unit. It seems to the speaker that there is danger in thus generalizing in advance of definite proof, or, at least, in letting our thoughts be guided as though this general proposition were true. A similar generalization was made without proof some years ago in Physics. I refer to the principle of the conservation of matter, which has been published in most textbooks on physics of the older school. We have latterly been obliged to retract this. We do not know now that it is true. We cannot assert, however, that the contrary is true, namely, that matter is being created and destroyed. We simply do not know. We do know that the individual atoms do not remain intact as they were formerly thought to do, and that some of them are actually going to pieces, giving out parts of themselves and losing weight. Whether or not the electrons that they give out always enter into some other piece of matter, and thus make for the ultimate conservation of matter, it is not possible to say. We cannot say that the sum total of electrons in the universe remains constant.

You will easily comprehend that the effect of Planck's theory has been to divert attention from electromagnetic theory, since he was forced to lay it aside. This very act, and the fact that substantial progress was made by so doing, naturally brought

electromagnetic theory into disrepute, so far as its application to electrons in atoms is concerned. It is fortunate that he had the courage to do it, because the result has been that we are in possession of valuable information about the atoms, which would otherwise now be unknown.

It must be admitted, however, that it will never be satisfactory to the human intellect to leave the situation in the state we find it today. The solid foundations upon which we must seek to found an atomic hypothesis should in some way be connected with the properties of the electron and its connection with the ether of space. These are fundamental parts of electromagnetic theory, which expresses in mathematical language just this connection between an electrical charge and the ether, that is, between matter and the ether. It even seems possible, nay indeed probable, that some good reason for the existence of a quantum of energy may yet be discovered by the help of electromagnetic theory, as being connected with the very constitution of the atoms themselves. This hope alone is sufficient incentive to urge us to continue the search by the use of this theory, at least to such a point that it can be proved the search is vain, a most difficult undertaking.

You perceive from the above remarks, when taken in connection with the title of this address, "Some applications of electromagnetic theory to matter," the difficult nature of the role that the speaker has assumed. Having come to a decision to apply electromagnetic theory, so far as possible in all strictness to the electrons in the atoms, for the purpose of learning where it gives a good account of itself, and where it requires some modification, I have gradually been led to the conclusion that comparatively little has heretofore been done in this direction, and that the results thus far attained are of so great value that a great deal more should be done.

It is the under dog that has the sympathy of the crowd, especially if he shows sufficient life to put up a plucky fight. During the present phase of the wave of progress in physics, electromagnetic theory, as applied to the atoms is like the under dog. It is on the defensive, and there are strong reasons why those who are striving to save it should have the sympathy of the crowd.

II. Rutherford-Bohr Atomic Theory

With this introduction you may be better prepared to listen to the following account of some applications of electromagnetic

theory to matter. As above stated the Institute had the opportunity last year to hear an address upon topics of absorbing interest to physicists, which included some account of the Rutherford-Bohr theory of the atom. This theory is, no doubt familiar to you, but some of the chief features of it will form the starting point of my remarks tonight. According to their theory an atom is a structure composed in part of a charge of positive electricity, the center of which is the geometrical center of the atom. This charge is supposed to have small dimensions compared with the size of the atom, or even of the negative electron. Around this nucleus one or more negatively charged electrons are supposed to be describing approximately circular orbits, the radii of which are very large as compared with the radius of the electron itself.

There may be several electrons describing the same orbit at the same time. They would then distribute themselves at equal intervals around this orbit on account of the mutual repulsion they have for each other, thus forming a ring of electrons. The atoms may be composed of several such rings all circulating around the same nucleus. Atoms, in the ordinary states of matter, have no resultant charge, and it is supposed that in this case the sum of the negative charges of the electrons is equal to the positive charge of the nucleus, thus making the total zero, when the atom is said to be neutral. Under special circumstances atoms may be caused to lose or to gain one or more electrons than they have when neutral, and then the atom manifests a resultant charge, positive if electrons are lost, negative if gained. It has been observed that such atomic charges are always some exact multiple of the charge on one electron, but it may be either positive or negative.

There are certain remarkable features in this theory introduced by Dr. N. Bohr, relating to the changes which take place in such an atom when it is disturbed by any cause. He finds that the radius of the orbit of the electrons changes from one fixed value to another, there being a series of possible radii; but, when the change begins, it does not stop until it arrives at one of the other possible radii, or, in other words, the radii must change by sudden jumps. This is a direct result of an application of the quantum theory above referred to to the atoms; for, by it, the change in energy must take place in quanta. Bohr has found as a result of his premises that there is a change in the kinetic energy of the electron in passing from one of these fixed

orbits to another, and the size of the orbits has been calculated from *electromagnetic theory* by taking this change in the energy always as an exact multiple of the quantum of energy. The atom will then radiate energy when the electrons fall in towards the nucleus from one fixed orbit to another, and they absorb energy when they go outwards from the nucleus.

There are several assumptions that have been introduced in order to arrive at these results. First there is no radiation of energy at all when the orbit remains in one of the series of fixed positions, although the electrons are in rapid motion. Second the ordinary equations of electromagnetic theory apply to the electrons when they are in one of these fixed orbits not radiating energy, but that they do not apply when they are changing over from one radius to another and radiating energy. There have thus come to be recognized several states of the atoms, where the radii are fixed, known as the steady states, and where energy is neither radiated nor absorbed. All other states than these exist only during the radiation or absorption of energy.

III. Two Great Natural Divisions of Matter

There is thus made a great natural division of all existing physical phenomena. The atoms are either in one of these steady states or they are not. To illustrate, we may consider that most of the matter in the solid crust of the earth is in the steady state, or, more strictly, it would be if it were at the absolute zero of temperature not radiating any heat. It is quite conceivable to think of the temperature of the earth as being lowered to the absolute zero without disturbing in any way the real constitution of the rocks of which the earth is composed, or of the temperature of a crystal being at the absolute zero. As an example of atoms not in the steady state, we may think of substances during the process of undergoing any chemical reactions, where a change of partners takes place with an accompanying transfer of energy among the atoms and molecules. This includes all vital processes in organic substances, where chemical reactions are continually taking place under certain special laws of guidance or causation. This latter class involving energy transfer includes most of the phenomena of the greatest interest to man, but the former class, the steady state, is of the utmost importance even if somewhat more restricted in variety. We owe to it the home in which we live, the solid structure of the earth. It also includes the large class of metals and building

materials generally, in which the engineer is particularly interested.

It may be repeated, that, in this first class, the steady states, the Bohr theory, and other theories, assume that the ordinary electromagnetic theory is applicable to the electrons in an atom. The view is taken that it is not applicable to the second class involving energy changes in the Bohr theory, but it might be a better position to take to say that no one has as yet seen just how to apply the theory than that it is not applicable.

If we, therefore, confine our attention to those states of matter where there is no energy transfer, the first class, where the electromagnetic equations are said to apply even by those who indorse in every detail the Bohr theory of the atom, we ought to be able to make a beginning of progress in interpreting some of the physical properties of this class of matter by the correct application of electromagnetic theory. It is time enough to begin a consideration of the other necessarily more complicated class, where there is a transfer of energy, and where the applicability of the electromagnetic equations is at present in doubt, after we have achieved some sort of results in the simpler case. It seems as if this simpler case should naturally precede any consideration of the other, for one reason, because any success in the one is almost sure to shed some light upon the methods of procedure to be adopted in the other.

It is precisely to these steady states of matter, where the applicability of electromagnetic theory is admitted, that the speaker has been endeavoring during the past several years to apply the present form of electromagnetic theory in a more rigid manner than it has been applied heretofore, and it is to a consideration of some of the results of such application that your attention is directed in these brief remarks.

IV. Electromagnetic Theory

To begin with a few remarks upon the current form of electromagnetic theory seem to be required. Engineers may be disposed to associate the words "electromagnetic theory" with that form of the theory which comes into the subjects of Electricity and Magnetism, as it is taught in the technical schools. There is a very great difference, however, between the general form of the theory and that part of it which is commonly needed for a complete understanding of all of the phenomena usually met with in electricity and magnetism. You will see at once the

reason for the difference when you consider that you are always dealing with great numbers of electrons instead of with single isolated ones. An electric current is a continuous stream of electrons often moving in closed curves, which evidently simplifies matters very much, and in every practical case, you will find that a simplified form of the theory is all that you require. For this reason it seems fair to assume that most of you are not very well acquainted with the general form of the theory where single electrons are concerned. The example referred to by the use of the electric current may make the difference clear. Imagine a closed circuit of any shape carrying a steady current. There is a magnetic field set up in the whole region surrounding the circuit, and at each point of this field the magnetic force is a directed quantity, but the point I wish to make is that it is constant at each point of the field. Now imagine all but one of the procession of electrons circulating around the circuit to be removed in some way, so that a single electron instead of a multitude passes around the same circuit. It is evident to anyone that the magnetic force at the point in question cannot be constant as before, but must be pulsating in character with a fundamental period equal to the time of revolution in the circuit. The equations of the general electromagnetic theory must be such that they will give a complete description not only of the variable magnetic force at the point in question with time but of the electric force as well, for, when a magnetic force varies, as it must, it is always accompanied by an electric component, which in such a case as cited will also vary. The very great simplification in the force introduced by having the stream of electrons is, I think, made clear by this example.

The general electromagnetic equations in current use are of too complicated a nature to introduce into a talk of this kind, but I think that some things may be said of them which will serve our purpose. They are necessarily expressed in the language of vector analysis as always dealing with variations of directed quantities in space, and no attempt to put them into other mathematical language that we possess will ever be successful. In fact, until the vector language was developed it was hopeless to cope with such problems. Let us now try to get a definite picture of some of the fundamental facts of electromagnetic theory as applied to just two electrical charges, two electrons if you please. Imagine them isolated from the rest of the physical universe if you can. If each of them is at rest, the

ordinary electrostatic force, with which you are familiar, is all that we have to consider, a repulsion in the direct line joining the charges inversely as the square of the distance between them and directly as the product of the charges. But, let them be set into motion. We may now picture a disturbance, sometimes called an electromagnetic wave, as travelling out in all directions with the velocity of light from the charges. If the distance between the charges is considerable, it may be quite a time before the wave from the one reaches the other charge, 8 minutes if one is in the earth and the other on the sun. In 8 minutes the first charge will have moved a considerable distance if its velocity is great. If its velocity were 1/100th of that of light, it would have travelled 1/100th of the distance from the earth to the sun in this time. So, when the wave that left it in its first position actually reaches the second electron, the first electron is not very near to the place that it was. In what direction would the force on the second electron due to the first then be? Evidently not in the original direction it had when they were both at rest. Electromagnetic theory purports to tell us just what the force is at any time on the one charge due to the other, that is the instantaneous force, for it is evidently continually varying.

You will, I think, see from this that the force on the second electron is entirely due to this electromagnetic wave which emanates from the first electron. This wave must travel in a medium, and so electromagnetic theory is founded upon the real existence of an ether fixed in space, and the force upon the second electron is really due to some connection that it has with the ether. One of the fundamental equations in electromagnetic theory expresses in mathematical language this fundamental connection that there is between an electrical charge and the ether. Much more might be added on this topic but, if you are to hear the things I have set out to say, we must pass over this phase of it.

V. First Application of Electromagnetic Theory

It will be understood that electromagnetic theory is perfectly general in that it expresses the force at a single instant of time only and does not prescribe at all how the two charges in question shall move relative to each other. We have been led to believe for many reasons that electrons revolve in approximately circular orbits in the atoms. The Bohr theory above referred to assumes this as the natural stable condition. Granting that

this is true, it must be evident to you that the first step in the application of electromagnetic theory to atoms should be the solution of the problem of finding the force that one electron when revolving at a uniform rate in a circular orbit, exerts upon a second electron revolving in a different circular orbit. These orbits must also be fixed in space in perfectly general positions, because the electrons in different atoms are, of course, situated in every possible manner.

It has been the speakers contribution to this subject to solve this problem in its most general form, no terms of any kind having been omitted. It may not, at first, be apparent to you that any solution is required, or rather, perhaps, of what a solution consists, since the general theory gives the force of one of these electrons on the other. But you will see with some further consideration that the equation we want must contain several quantities, the radii of the two orbits in question, the values of the constant velocities of the electrons in the orbits, the location of the position of the center of the second orbit in space with respect to the first, that is the x, y and z coordinates in ordinary geometry, and finally the relative positions of the planes of the two orbits, whether parallel or not. All of these quantities must find a place in the final solution, and of course none of them finds a place in the original general equation for the simple reason that it is general, not specifying any orbits or any positions for them. It requires three full pages to print this equation, but events have shown that it contains most important consequences when applied to electrons in atoms. It is some of these that I propose to discuss. The question probably occurs to you how could it have been claimed before that electromagnetic theory had been applied to electrons until the solution of this general equation had been obtained. This is a part of my contention in support of the view that these claims have not been very well founded, and that there remains much of value to be done.

VI. Rings of Electrons

In giving an account of them I shall not follow the order in which the results were obtained, but prefer to review them, as it were, with hindsight instead of foresight. Naturally one of the first things to do with this equation is to apply it to the particular case where the two orbits in question exactly coincide, the two electrons then being in different places in the same orbit, for, in this way we may learn something of the properties of

rings of electrons, of which the atoms are supposed to be composed.

A very great simplification is naturally made in the general equation when the two orbits coincide because the coordinates of the center of the second orbit referred to the first are all zero, and the speeds of the two electrons are the same. So the equation reduces to a very manageable form. The *total* force of the second electron on the first may then be conveniently resolved into two components, the one along the radius of the orbit, and the other along the tangent line perpendicular to the one. In general, neither of these components of the force is zero, and, as we make the velocity of motion less and less, the force reduces to the ordinary electrostatic force.

a—Two Electron Atom. If there are only two electrons in the ring, it is evident that they must take positions at the extremities of the same diameter of the orbit on opposite sides of the nucleus of the atom, which may now be imagined at the center. For a stable position, both the radial component of the force and the tangential component must vanish, otherwise there would result both a change in the radius of the orbit and an acceleration along the orbit, neither of which conditions represent a steady state. In such an atom, consisting of a nucleus and just two electrons, I have calculated the total radial force on one electron, including that due to the nucleus, that due to the other electron and that due to the centrifugal force of the electron itself. This is shown in the curve *I* on the slide. The equation for the radial force is

$$F_\rho = e^2\left(-\frac{7}{4a^2} + \frac{\beta^4}{2a^3}\right) + \frac{m_0 v^2}{a}.$$

There are two radii at which the radial force vanishes, the one about 2×10^{-10} cm. and the other at 1.85×10^{-8} cm. In between these values the force is negative, signifying an attraction of the electron towards the nucleus, and, for all values greater or smaller than this, the force is positive signifying repulsion. From this it is evident that the larger root corresponds to an unstable position, and the smaller root to the only stable position. This result entails some very radical consequences as regards atomic theory, some of which must be referred to here.

In the first place it makes the order of magnitude of the radius of the orbit of the electrons 10^{-10} instead of the much larger order 10^{-8} cm. given by the Bohr theory.

In the second place, by omitting the forces due to the ***motion*** of the rings of electrons, the $e^2 \beta^4/2 a^3$ term in the equation, and by taking into account the electrostatic forces only, and balancing these against the centrifugal forces as Bohr does, the ordinary conditions for planetary motion as in a solar system obtain, except that there is repulsion instead of attraction between the planets. He has made use of the following theorem which applies quite generally to all such systems "In every system consisting of electrons and positive nuclei, in which the nuclei are at rest and the electrons move in circular orbits with a velocity small compared with the velocity of light, the kinetic energy will be numerically equal to half the potential energy."

It is the use of this theorem that has to be abandoned because of the neglect of the forces due to the motion of the ring. By the help of this theorem Dr. Bohr was led to adopt the equal angular moment of momentum hypothesis for each and every electron in all atoms, which he stated as follows, "in any molecular system consisting of positive nuclei and electrons in which the nuclei are at rest relative to each other and the electrons move in circular orbits, the angular momentum of every electron round the center of its orbit will in the permanent state of the atoms be equal to $h/2\pi$, where h is Planck's constant." This theorem is derived directly from the preceding theorem and fails when it fails.

The reason for obtaining such different results by a strict application of electromagnetic theory is apparent. The difficulty at the time Dr. Bohr first published this theory in July 1913 was that there was no available expression for the forces due to the motion of the ring, but now, the general equation referred to above has supplied this. It appears that there is a term in the force $e^2 \beta^4/2 a^3$ due entirely to the motion of the ring, that coming from the magnetic component in the general equation, which varies inversely as the third power of the radius, and directly as the fourth power of the velocity in terms of that of light. This term has not been pointed out before. It is a repulsive force and very small at distances anything like 10^{-8} cm. but, because it varies as the inverse cube of the distance, it is evident that it rapidly increases the smaller the radius, and must overtake in size any term that varies inversely as the square of the distance, namely the electrostatic forces that Bohr used. It is where the balance between these two kinds of terms is effected that we obtain the stable position of the orbit.

For complete equilibrium, as was stated, the tangential force of one electron upon the other must also vanish. This subject has been discussed in that now classical work on "Electromagnetic Radiation," by G. A. Schott. He has derived an expression for the sum of the forces upon one electron in a ring due to all the others in the ring, but it is not given in a form that is easy to use, involving as it does the use of Bessel's functions, and summations. However, our two results are based upon the same premises, although expressed in different form, and they should agree. They do agree in so far as a comparison has been possible, which gives some assurance that both are correct. Now these tangential forces can never be zero as Schott points out, unless we also take into account the force that the one electron exerts upon itself. The other electrons in the ring exert forces on the one in such a direction as always to accelerate the motion of the one electron, thus doing work upon it. The one electron exerts an exactly equal and opposite force, and thus makes the total tangential force zero. In other words it requires some energy to keep the ring in motion. Strangely enough, however, it requires much less the greater the number of electrons in the ring.

b—Regulation of Speeds of Rings in Electromagnetic Theory.

In electromagnetic theory, it is not possible to conceive of a single electron moving alone through the ether, sending out from itself a wave of energy in all directions and still keeping up an undiminishing velocity, unless the electron is itself changing in some way. There must be a source of this supply of energy, to supply the energy radiated, and lost to the electron. Schott has accounted in a beautiful manner for the regulation of the speed of electrons in rings. The regulator acts through the medium of these tangential forces, and Schott has shown that the peculiar nature of these forces is such that the velocity of the electrons in a ring will remain substantially a constant, or subject to very small variation for comparatively great changes in the radius of the orbit. This refers to the actual, not to the angular velocity.

It is not easy in a talk of this kind to carry you along so that the reasons for certain conclusions have much force, partly because there are many related matters that have a direct bearing upon any given one. Suffice it to say here that there are strong reasons to believe that the regulation of the speeds of rings of electrons is accomplished in the manner indicated by

electromagnetic theory as pointed out by Schott. The ground is taken here that this loss of energy by radiation is excessively small, too small to be detected by any means as yet at our disposal, and that no observations connected with the quantum theory are in the least affected by its existence.

c—Velocity of the Ring.

d—Line spectra and Rydberg's Constant.

Let us next consider some of the consequences of the law of radial force which you have seen in the curve. It may now be stated that, in order to get this curve numerically, the velocity of the electron in its orbit had to be known for the different radii, and, in accordance with the above statement, the velocity in the orbit has been taken as approximately constant for all radii between the two roots of the equation. The velocity of an electron in any ring, according to these ideas, may always be taken equal to $p\frac{\pi^2 e^4}{h^2}$, where p is the number of electrons in the ring, e the charge of the electron, and h Planck's constant. The justification for the use of this value is that it leads to precisely the same equations for line-spectra of hydrogen and helium as Bohr gives, which agrees very closely with observed spectra. It may be remembered that the derivation of Rydberg's constant (the constant connected with light spectra) in terms of the charge on the electron and Planck's constant has been one of the most cogent reasons for adhering to the Bohr theory. The expression for Rydberg's constant is

$$K = \frac{2\pi^2 m_o e^4}{h^3}$$

The force of the argument is that, when the values of the constants on the right determined by physicists in a number of different ways are substituted in this expression, we obtain a number 3.294×10^{15}. The Rydberg constant, obtained by entirely independent observations on light spectra is found to be 3.290×10^{15}. Unless this expression were based upon a truth the chances are that no such agreement as this would be found. I will not be able to devote the time here to a demonstration of the following statements, but will merely state that the modifications above discussed lead to precisely the same expression for Rydberg's constant as the above, including also the equations for the line spectra of hydrogen and helium. The new ideas are thus not a step backwards, but,

when it is stated that I get in a similar manner to the above an expression in terms of the properties of the electrons for the Newtonian constant of gravitation that agrees just as closely with the value of this constant as determined by the astronomers, it will be seen that this, when added to the Rydberg constant greatly strengthens our position, thus being a step forward.

e—Energy of Separation of Ring from Nucleus. We may easily calculate from the force-curve the energy that is required to separate the ring of electrons from the nucleus from one radius to another separating both electrons together. This energy curve is shown as curve II. A minimum point of the energy curve occurs where the force is zero. From this point outwards we have to supply the energy to pull the electrons away from the nucleus and from each other, but beyond the larger root (not seen on the chart) where the force changes sign to a repulsion, the system will do work upon the electrons. Suppose, for example, that we supply from some outside source enough energy to separate the electrons from their normal orbit at 2×10^{-10} to 1.85×10^{-8} cm. The electrons will arrive there with little or no velocity, all of this energy having been used up, but, after that, the repulsive force of the system begins to act, and it will accelerate the outward speed of the electrons until the fixed amount of energy which corresponds to the separation from 1.85×10^{-8} to an infinite distance has all been converted into kinetic energy.

VII. Electrons Ejected From Atoms With High Velocity

It is calculated, in the particular case of the ring of two and a nucleus of two, that the velocity thus acquired is nearly 1/20 of the velocity of light. With a ring of four and with a larger nucleus, the velocity will be greater than this.

In radioactive substances it has been experimentally observed for some years that electrons are projected out from them with velocities that approach very close indeed to that of light, 98 or 99 per cent of it. In the atoms in their normal condition it has never been supposed that the electrons have velocities anything like as great as that of light, and this theory has now given a valid reason why there may be a great increase in the velocity when electrons are ejected from atoms.

VIII. X-Ray Spectra

In the Bohr theory as has been stated above, there are supposed to be several steady states of the orbits which differ

according to the values of an integer, τ. In his theory the radii of these orbits increase with τ, as the squares of the integer, 1, 4, 9, 16, etc., and there is supposed to be a definite change in the kinetic energy of the electron from orbit to orbit. All of these results came about due to the neglect of the forces due to the motion of the electrons. When these are taken into the account, we have no change in kinetic energy from orbit to orbit, but the energy change is of the nature of potential energy, the work done in separating the electrons against the radial forces shown by the curve. It may be stated that we now get a very different series of radii from those of the Bohr theory. The radius of the orbit for all values of τ from one to infinity never departs very far from the minimum point of the energy curve. We can find these radii corresponding to any value of τ by drawing a horizontal line across at a height just above the minimum point of the curve equal to the known value of the total energy to separate the electron to an infinite distance from the nucleus. Such a line is drawn in the second slide, which shows this same minimum point of the energy curve to an enlarged scale. Lines are drawn for $\tau = 2$, 3 and ∞, $\tau = 1$ corresponds to the minimum point itself. Each line cuts the curve in two points, and each point of intersection corresponds to the proper radius of the orbit for that value of τ. Instead of a single value of the radius as in the Bohr theory there are two possible values.

I fully realize that it is not possible to make the reasoning on this matter appeal to you in the brief time at my disposal, but these results carry such important consequences that I could hardly avoid referring to them. They throw much light upon an experimental observation that has received no good explanation in terms of atomic theory. I refer to the charts of the x-ray spectra of the elements as observed by Moseley. These were shown here last year I believe. Moseley shows a group of four lines close together which he has named the α, β, ϕ and γ lines in the L series, and in the K series, the α and β lines. There has never been any clear understanding why there should be such a grouping of lines in the x-ray spectra. This theory gives a reason for it, and enables us to approximate to the positions of the lines. Bearing in mind that the orbital velocity is constant for varying radii, and that the velocity in a circular orbit is equal to $2\,\pi\,a\,n$, it is evident that the orbital frequency is inversely proportional to the radius in this theory. So also is the x-ray frequency inversely as the wave length, λ. If,

then, the x-ray frequency is connected with the orbital frequency in a proportional manner, which is very probable, then the x-ray wave lengths should be proportional to the radii of the orbits. A comparison between the observed wave-lengths for the element europium, which happens to be the heaviest element for which Moseley has shown all four lines in the L-series, and the radii as estimated for values of $\tau = 1, 2, 3$ and ∞ is shown in the next slide. The general agreement is too close to be purely accidental.

In support of this view of the origin of this group of lines is the fact that they all run along in a parallel fashion without any cross-overs or intersections. You can see by the way the spacings are derived from the energy curve that any intersections of the lines in Moseley's chart would be fatal to this view of the matter. There is another interesting matter that this explanation involves. The radii for $\tau = 1$ are slightly larger than for $t = \infty$, so that the radii decrease slightly instead of increase for an increase in τ, but the amount of the total change is quite small. That is, we use the values on the left of the minimum point of the energy curve instead of those on the right. In the Bohr theory the radii increase with τ, and as the squares of the integers, as 1, 4, 9, 16 etc.

IX. Ionizing Voltages

Without attempting here to give any derivation of it, I will merely state that the theory gives a formula of a very simple kind for the voltages that are required to ionize a gas and to start radiation. This is limited as yet to gases having atoms with single rings of electrons like hydrogen and helium. A considerable amount of experimental work has been done recently on hydrogen on account of the interest in it from the standpoint of the Bohr theory. The voltages required the tear electrons off from the nucleus and to drive them entirely away from the atom, thus leaving the atom charged and making what is called on ion of it, can be measured experimentally. The theoretical formula is

$$V = 3.3844 \times \frac{p^2}{\tau},$$

where p is the number of electrons in the ring and τ an integer. This subject alone is large enough to occupy the whole evening. if it were gone into in detail, so we must content ourselves with

saying that the theory gives all of the values approximately for hydrogen that have been observed, including a very recent value between 15 and 16 volts which the Bohr theory gives no account of. It also gives values for helium much nearer to the observed values than the Bohr theory. It seems, however, that helium has not been so exhaustively investigated experimentally as hydrogen in this respect.

X. Theory of Crystal Structure

Let us now pass to some results of a very different kind that have been derived from the general equation. I refer to the theory of crystal structure. By means of the x-rays you are aware that it has been possible to find the exact location of the centers of the atoms of which a crystal is composed. This method was discovered by Prof. Laue, and first published in a paper by Laue, Friederick, and Knipping. I shall confine these remarks to a few of the simplest forms of crystals belonging to the cubic or isometric system. In all of these the general arrangement of the atoms is in equilateral triangles in a plane. The whole crystal is built up by many separate planes of atoms all similarly arranged in each plane. I have brought here a number of models to help give you an idea of the space lattice arrangement in four of the important classes of crystals belonging to the cubic system. Without models it is not very easy to make much progress in understanding crystal structure. In each one of them you will observe that the fundamental arrangement is the equilateral triangle. The several planes of such triangles are related in several possible ways, which makes the characteristic differences in the resultant space lattice.

a—Directions of Axes of Atoms in a Crystal. According to our ideas of atoms each has an individual axis of revolution, being determined by the common plane of the orbits of the electrons revolving around the nucleus. If we fix the attention upon just two atoms whose axes point in different directions, the equations of electromagnetic force show that there is a tendency of the one atom to turn the plane of that of the other until they become parallel to each other before complete equilibrium is established. Now the angle between the directions of the axes of the two orbits is one of the quantities that is contained in the general equation, and unless we know the directions of the axes, we cannot calculate the force by means of that equation.

Fortunately, it has been possible to find the directions of all

the axes of the atoms because of the symmetry of the crystals, coupled with the knowledge that each atom in the whole structure tends to turn the direction of the axis of rotation of every other atom. Any one atom feels the turning effect of all the others, and it is only the resultant of them all that determines the position of any given axis. Now, without knowing how much the tendency to turn the axis is, it is evident that if three atoms, which are just alike, are placed at equal distances from the given atom having their axes properly directed, they may annul one another and have no turning effect upon the given atom. Without going into the history of all the troubles that presented themselves before a solution of this question was found, I have a model which shows you an arrangement of the axes of the atoms in one of the equilateral triangular planes, and can prove to your satisfaction that this particular arrangement makes the total turning moment hold each axis in the crystal in just the position indicated by this model. In this model there are only four directions of the axes. One quarter of them all is parallel to one given direction, a second quarter to another, and so for the whole. These four directions are the directions of the medial lines of a regular tetrahedron, or, which is the same thing, the four diagonals of a cube. I have placed colored strings in the models, one string passing through each atom to indicate the direction of its axis in exact accord with the plane model. You will find upon studying the models that each of the parallel planes has atoms with their axes arranged exactly like the plane model. Taking all these planes together you see that every atom has the direction of its axis fixed. But, again, you will observe that each model can be turned in any one of four different positions so that a different set of planes each time makes up the whole crystal. And no matter in which of these four ways you turn the model the relative directions of the axes is precisely the same as in the plane model. In doing this we have really counted each atom four times, and every time the direction of its axis is right. Had some different arrangement of the axes been adopted for the plane model it would not have turned out that you could turn these models in any one of four directions and then found that the individual planes were the same as in the original model. In other words the possible number of arrangements of the axes in any plane is very limited, and it is my belief that this is the only possible arrangement that will satisfy the condition that the turning moments shall be zero.

b—Order of Magnitude of the Radii of the Orbits. Having found the directions of the axes, but not before, it is possible to apply the general equation to determine the total force on an atom due to all the rest in the crystal. When the expression for the force thus obtained is equated to zero for the stable equilibrium condition, the only two unknown quantities that remain are properties of the atoms themselves, viz., the sum of the squares of the radii of the orbits of the electrons in the atom in question on the one hand, and the sum of the products of the radius by the velocity for each.

In other words, starting from the known dimensions of the space-lattice forms in certain crystals, and knowing the kind of atoms there are at each point of the lattice, we may, by an application of electromagnetic theory, arrive at some knowledge of the sizes of the orbits of the electrons themselves within the atoms.

Without giving you the process in detail, the results may be briefly stated. The sum of the squares of the radii found in this way show a gradual increase with heavier and heavier atoms according to a definite curve, but the order of magnitude of the radii lies between 10^{-10} and 10^{-9} cm. This agrees well with the value found in an entirely different way for hydrogen.

c—Some Kinds of Atoms Show Two Possible Values of Their Radii. This theory has been applied to twenty different crystals, minerals, containing in all as many separate elements in different combinations. The same element, say chlorine or sulphur, occurs in several of these crystals. It may be regarded as a confirmation of the theory that the same values are obtained for the same kind of atom no matter in which crystal it occurs. This brings out a point of very great interest, because the above statement is not universally true. For example, the element sulphur occurs in four of the crystals, zincblende, ZnS, iron pyrites, FeS_2, manganblende, MnS, and galena, PbS. We get the same value for the radii for the sulphur atom from three of these crystals, but a different value in galena, PbS. The numerical relation between the sums of the squares of the radii in the two cases is $2^{4/3}$, the sulphur in galena being of smaller radius than the others. In a similar manner several other crystals give different values for the same element, and they always differ by precisely this same factor $2^{4/3}$. The result is very suggestive as indicating that the same atom may have at least two different states, differing in the size of the radii of the

orbits, but without affecting the weight. It is possible to see by looking back at the equation for the radial force for the single ring of two electrons, where there were two roots at each of which the radial force is zero, that the more complex equation for atoms with several concentric rings might give more than two roots, and of these there might be more than one stable position for the radii. This is a thing that we might expect from our knowledge of atoms in chemistry. There are different kinds of sulphur atoms, having different valencies, and so with some other atoms. It is most important to observe though that the weights of these atoms are the same. Electromagnetic theory throws much light upon this matter, as we shall presently show.

d—Rigidity and Bulk—Modulus. We will conclude the remarks on crystals with the statement that the forces which have been obtained give a very good reason for the rigidity of crystals, and the resistance they offer both to change of shape and change of volume. The estimated value of the bulk modulus is of the same order of magnitude as the experimental values.

XI. Atoms at a Great Distance

There is another matter to which the general equation has been applied, which I have left until the last, although it would have been most natural to place it first, as being perhaps the simplest application of the equation. The question is what effect will two atoms have upon each other according to the equation when the distance between them is very large, say one centimeter or more. It may be shown that all of the electrostatic forces between two neutral atoms at a great distance exactly cancel out until we come to terms involving the inverse sixth power of the distance. Each atom has in effect a zero charge at these great distances, and the only part of the forces that we have to calculate arises from the *motion* of the electrons in their orbits. In the final analysis, therefore, to get the whole mechanical force between the atoms, we have to find the average mechanical force that one single electron in the second atom exerts upon another in the first atom. The total force is evidently merely the sum of a number of such expressions, the number depending upon how many different pairs of electrons there happen to be in the two atoms considered. If it happens, as it does, that the force due to any one pair of electrons gives us a quantity that is *not* cancelled out by that due to another pair, we obviously get a

real resultant force between the two atoms. We know that such a force exists in fact, the gravitational force, and we should be interested to compare the force given by the equations with the actual known force.

a—Problem of Two Electrons. Average Force. In order to solve this problem for two electrons only it was necessary to obtain the average force between the two electrons taken over a very long time, a large number of revolutions. The only way as yet found to do this is to develop the equation into an infinite series of powers of the distance between the centers of the two atoms, and then average the separate terms. The result is that the series contains all powers of the inverse distance between centers, beginning with the first power, and so on. Moreover, the force is not in the direction of the line joining the centers of the two atoms. This is easily understood when it is remembered that the force between the two electrons in the original equation is not in this direction.

b—Force Resolved Along the Line Joining the Centers of the Orbits. We are interested, however, in the component of the total force that is in this direction, and hence the total force has been resolved in the direction of the centers. The part at right angles to this does not interest us because it will all be cancelled out by the action of the electrons in other atoms turned in every possible direction.

Now it results in the process of resolving the force along the centerline, that the first term of the series, the inverse first power term, cancels out leaving it to begin with the inverse square, and higher powers. Moreover, because the distance between the atoms is assumed to be great, all of the inverse higher powers are evidently negligible, so that the total force varies inversely as the square of the distance between the atoms. The resulting force-equation is of sufficient interest to give in full.

$$F = \frac{1}{2} e_1 e_2 \beta_2^2 \{1 - (-X \sin \alpha + Z \cos \alpha)^2\} r^{-2}. \qquad (1)$$

Here e is the charge on the electron; β_2 the ratio of the velocity of the second electron, the force of which we are getting, to that of light; X and Z are direction cosines determined by the position of the center of the second orbit; α the angle between the directions of the two axes of rotation, and r the distance between the centers of the orbits.

c—Simplification of Result in Case of Two Masses of Matter. Let us apply this equation to two electrons, one in each of two

atoms of any gas, liquid or solid, crystals excepted. At any given moment the axes of the two orbits may be turned in any possible directions relative to each other, so that the theory of probabilities must be applied, because it is the force on the average that we require. When this is done, it is shown that the quantity within the brace becomes 2/3, and hence the average force on the first electron due to the second becomes the very simple expression

$$F = \frac{1}{3} e_1 e_2 \beta_2^2 r^{-2}. \tag{2}$$

This expression is in the form of the law of gravitation in two respects. First, it always gives an attraction, and second, it varies inversely as the square of the distance. Before inquiring into the magnitude of the force, let us apply the equation to the only kind of matter not included above, namely crystals.

d—Attraction Independent of the Orientation of the Axes of a Crystal. We have seen that there are but four different directions for all the axes of the atoms in a crystals so far as the theory of crystals has been developed. Would we obtain the same result as before using these four directions only? If not, the theoretical attraction between two crystals would show some differences at the same distance when they are turned about in different directions. The experimental evidence is that the gravitational attraction shows no difference in any direction, and, consequently, if the force is to be identified with that of gravitation, it is necessary that the terms involving the directions of the axes in this parenthesis should give the same result as above even in the case of a crystal. It has been possible to show that they do, and this circumstance is due to the fact that the axes in the crystal are all parallel to the four medial lines of a regular tetrahedron.

e—A New Geometrical Theorem Obtained from Physical Considerations. There is an interesting incident in this connection. The equation showed that the following geometrical proposition must be true if the force is to be independent of the orientation of the crystal. "If through any point in space four lines be drawn making equal angles each with any other (that is parallel with the four medial lines of a regular tetrahedron) and, if from a second point in space, at a distance r from the first point, the four perpendiculars be drawn, one to each of the said four lines, then the sum of the squares of these perpendiculars is constant for all points at the same distance

from the first point." The quantity within the brace of equation (**1**) is equal to the square of one of these said perpendicular lines.

The truth or falsity of this proposition was unknown at the time of arriving at the conclusion that it must be true if this is the proper form for the gravitational force. It has since been proved to be true,* and this has added a new geometrical theorem to the list, as it was unknown to the mathematicians to whom it has been submitted. This incident of a mathematical theorem deduced in this physical way helps to show that we may be on the right track in understanding the cause of the force of gravitation.

We see, therefore, that the force tallies in every way with the gravitational force except in the matter of magnitude, which will next be considered.

f—Magnitude of the Force. As you have seen above in considering hydrogen, we have a knowledge of the probable speed of the electrons, and there is nothing else in doubt that we need for calculating the force, since the charge on the electron is known. Using these known speeds, the force calculated from this equation comes out about 10^{31} times greater than the actual value of the gravitational force. This is an enormous error and cannot be accounted for by assuming any mistake in the velocity of the electrons used. The result is very significant at the same time because the calculation indicates a force 10^{31} times greater, ***not less***, than the actual existing attraction. It is a more fortunate result than it would have been had the calculated force come out the smaller of the two because then gravitation might easily be attributed to something else, but, as it stands, we are forced to question the truth of the hypotheses that have entered into the case. What are they? They are really but two. First, that the atoms are structures consisting in part of electrons revolving in circular orbits, or approximately circular orbits as you please. Second, that the modern Lorentz form of electromagnetic equations applies to the case.

We are not yet ready on the strength of any electromagnetic theory to abandon the idea that electrons describe approximately circular orbits within the atoms. It is easier to believe that some modification in the present form of electromagnetic theory is required. Let us look at the expression for the average force upon one electron in a circular orbit due to another a little more attentively. We have already seen that the expression gives a good

*The proof is due to Prof. F. W. Owens of Cornell University.

account of itself in many ways. It represents always an attraction, and not a repulsion, and obeys the inverse square law. It also shows that, when such forces are summed up for two crystals, the result is independent of the orientation of the crystals. In fact, it has the right look in so many ways that I have been led by natural steps to suppose that some very important factor has been omitted somehow from the Lorentz theory.

g—Equation of Force Unsymmetrical. You see by the expression (**2**) that the speed β_1 of the electron, upon which we are getting the force is not present, indicating that the force does not depend upon the velocity of the first electron. If we should write down the force of the first electron upon the second we would merely put β_1^2 in place of β_2^2. Therefore, unless both these velocities were the same, the force of the second on the first would not be the same as the first on the second. This has led me to suspect that the square of the velocity of the first electron should also appear in the force-formula. The order of magnitude of this is 10^{-4}, so that this alone could not possibly account for the discrepancy of 10^{-31} above mentioned. It reduces the discrepancy, however, to 10^{-27}. Now the mass of the electron itself at slow velocities is $.90 \times 10^{-27}$ grams. If the mass of the electron is also included, equation (**1**) takes the very symmetrical form

$$F = \frac{m_o}{2K} e_1 e_2 \beta_1^2 \beta_2^2 [1 - (-X \sin \alpha + Z \cos \alpha)^2] r^{-2}, \quad (\mathbf{3})$$

and the average force on one single electron due to another is

$$F = \frac{m_o}{3K} e_1 e_2 \beta_1^2 \beta_2^2 r^{-2}, \quad (\mathbf{4})$$

where m_o is the mass of the electron at slow velocities, and K, the specific inductive capacity of the ether, equal to unity, has been introduced for the sake of keeping the dimensions of the equation right.

h—When a Factor is Introduced to Make the Equation Symmetrical, the Force-Equation Agrees With the Law of Gravitation. By means of this equation we may easily show that the magnitude of the attraction agrees to a surprising degree of accuracy with the attraction obtained from the law of gravitation. It may be applied to any two masses of matter equally well, but I will illustrate it by calculating the attraction between two average atoms of hydrogen, because the atomic theory gives the velocity of the electrons in the atom. When the formula is to be applie

to two masses of matter containing a large number of electrons, it is only necessary to replace the β_1^2 by the $\Sigma_1\, \beta^2$, and the β_2^2 by $\Sigma_2\, \beta^2$, the summations being taken of the velocities squared of all the electrons in each of the two bodies in question. The formula for the total attraction between the two masses then reads

$$F = \frac{m_o}{3\,K}\, e_1\, e_2\, \Sigma_1\, \beta^2\, \Sigma_2\, \beta^2\, r^{-2}. \tag{5}$$

We have seen above that the value of β^2 for any single ring of electrons is $p\,\frac{\pi^2\, e^4}{c^2\, h^2}$, and the sum of β^2 for all the electrons in the ring is p times this. If we are writing the attraction between two atoms of hydrogen, the two summations in (5) are the same, and we get by substitution of the above value

$$F = \frac{m_o}{3\,K}\, p_{\mathrm{H}}^4\, \frac{\pi^4\, e^{10}}{c^4\, h^4}\, r^{-2}, \tag{6}$$

where the p_{H} denotes the number of electrons in the hydrogen atom.

If this force is to be identified with the gravitational force, it should be numerically equal to the attraction as given by Newton's law, which is usually written

$$F = k\, m\, m'/r^2. \tag{7}$$

Putting m_{H} in place of m and of m', as denoting the mass of the hydrogen atom, this becomes

$$F = k\, m_{\mathrm{H}}^2\, r^{-2}. \tag{8}$$

Equating (6) and (8), as being different expressions for the same force, the r^{-2} cancels out, and, dividing through by m_{H}^2, we find a value for k

$$k = \frac{p^4}{3}\, \frac{m_o}{m_{\mathrm{H}}^{\;2}}\, \frac{\pi^4\, e^{10}}{c^4\, h^4}. \tag{9}$$

The K is omitted because it is unity and does not affect the numerical value, and also because it is not at all certain that it should not also appear in the Newtonian equation (7). The value of k as determined by the astronomers is 666.07 $\times\, 10^{-10}$. In the right member occur constants that have been independently determined by physicists. The following values are those in current use,

$m_o = .90 \times 10^{-27}$ grams (From Bucherer's value of e/cm_o and Millikan's value of e)

$m_{\mathrm{H}} = 1.662 \times 10^{-24}$ grams. Millikan's value.

$h = 6.547 \times 10^{-27}$ Planck's constant. Millikan's value.

$c = 2.9987 \times 10^{-10}$ cm per sec. = velocity of light.

If with these values we use for e, 4.750×10^{-10}, we get the value of k exactly as determined by the astronomers above given by putting $p = 2$. This value of e is just *one half of one per cent* smaller than Millikan's value of e which is 4.774×10^{-10}. Values of e determined by other observers and by other methods vary from perhaps 4.65 to 4.81, and it is quite possible that 4.750 is a very accurate value of e. In fact, if it is admitted that equation (**9**) is a true relation, it will be a very accurate way to determine e itself, because the value of k is accurately known, and we would get a value of e^{10} with a fair degree of accuracy, and hence would have e with precision.

The fact that the number of electrons in the ring for the hydrogen atom, p_H, must be equal to 2 to satisfy the expression for k numerically is significant as indicating again that hydrogen has two electrons per atom.

The argument for this atomic theory, on account of the numerical agreement with the Newtonian constant, is of the same nature as the argument for the Bohr theory above mentioned, on account of the numerical agreement with the Rydberg constant; but it is doubly cogent, because both these constants are adduced from this theory.

i—Certain Features of Electromagnetic Theory Brought Into Question. It is for these good reasons that I have ventured to question the correctness of certain fundamental assumptions in the current form of electromagnetic theory. We are forced to question it or to abandon altogether the idea that the electrons describe circular orbits within the atoms. Of the two alternatives, I venture to think that the proper one has been chosen. As above stated, as we look back over the history of the development of electromagnetic theory from Maxwell's beginning to the present time, a process of gradual evolution has been at work. I had formerly supposed that the commonly accepted electromagnetic theory is complete as we have it, or finished, so to speak, but I have been led to believe that it is yet in its infancy. To avoid being misunderstood some further remarks on this subject seem to be required. The changes in the theory that seem to be demanded are not very great, and will probably not affect most of the applications of the theory. They relate more particularly to the inverse square of the distance terms, which only come into the account in such problems as we have been considering. It may seem impossible to you that any change can be made in the theory, because the equations already express

with complete satisfaction all the phenomena in the subjects of electricity and magnetism dealing with gross matter, with which we are acquainted. It was pointed out before that all these things represent very special cases, in fact, the older form of equations of Maxwell's day are just as good for these things. The applications to gross matter are not affected by the modern change in the introduction of the ideas of retarded potentials.

j—Direct Experimental Verification of Electromagnetic Equations Desirable, But Probably Impossible. We really need an experimental verification of the general electromagnetic equations. Prof. H. A. Rowland charged the circumference of a wheel and set it revolving at a rapid rate. He succeeded at best in detecting the magnetic force at the center, and showed that the magnitude agreed with the theory. What we really want, however, in order to test the theory is to have the charge at one point only of the wheel, and to measure the instantaneous, not the average, mechanical force upon a second electrical charge in its neighborhood both as to direction and magnitude. Needless to say this has never been accomplished and we may almost say never will be accomplished. We should need a recording apparatus that had no time lag, and that is capable of indicating a force in any direction equally well, and of a very insignificant amount. The conclusion is that we are compelled to resort to indirect methods of testing these equations. It seems that we may legitimately regard the process above described as one of these indirect methods. In such methods, if one assumption fails, we ought not to hesitate to try another, for the original theory itself rests upon assumptions that seem to us correct, but which can only be tested by the indirect method.

XII. The Results Obtained Above (XI) Agree With the Form of Atomic Theory Demanded by Electromagnetic Theory

The gravitational formula above is so simple, and has so many points in its favor that I have proceeded as though it were true, and have endeavored to find some of the consequences that it implies for atomic theory. We shall next consider some of these and you will note that they are in complete harmony with the conceptions of atomic properties that we have been considering. First, let us take the earth as one of the bodies, and a single atom on the earth's surface as the other body, and

write down the force of attraction according to the equation. We get the very simple expression

$$F = k\, \Sigma_A\, \beta^2. \tag{7}$$

where the constant,* k, involves the constant charge on the electron, the mass of it, and the summation of the velocities squared for the electrons in the earth, all of which does not vary when we substitute one atom for another.

a—The Weight of An Atom is Proportional to the Total Kinetic Energy of the Electrons it Contains, Relative to the Center of the Atom. Now this attraction is merely the atomic weight, and we, therefore, have the suggestion that the atomic weight is merely proportional to the sum of the squares of the velocities of all the electrons in the atom, that is, to the total kinetic energy of the electrons, and it should be added that the velocities must be those relative to the center of the atom. If the whole atom moves, this would add nothing to the weight because the effect of the positive nucleus would exactly annul that of the electrons. But, we know that atoms of the same kind, say hydrogen, have the same weight in a given locality. We may, therefore, conclude that the velocities of the electrons in the atom must always be the same in the different states of these atoms. This is in exact conformity with the theory of the atom above described. The velocity in any ring, according to electromagnetic theory, is a constant quantity dependent upon the number of electrons in the ring. So long as we leave the rings in an atom undisturbed they must always have the same velocity, but, when we change the number in the ring the velocity must suddenly change to a new value, and then the weight will change. We then really have a different atom. It has suddenly changed over to one of a different class.

The atomic theory above outlined also shows that any ring may change its radius without affecting the velocity of the electrons, the kinetic energy remains fixed independent of changes in the radius. The Bohr theory, on the contrary, demands a change in the kinetic energy with any change in the radius. On the one hand we keep a constant weight, and in the Bohr theory the weight must change, if the weight has anything to do with the kinetic energy. But it is a matter of measurement that the weight does not change. I may refer again to those crystals in which the same kind of atoms, sulphur for example, are re-

*This is not the same constant as the Newtonian constant above.

quired to have different radii in different circumstances, although the weight remains the same. This is in accord with the modified theory.

b—The Weight of any Ring of Electrons in an Atom is Fixed Independent of its Radius, and Always Contributes the Same Amount Toward the Total Weight of the Atom. According to these ideas, therefore, a ring of two, three, etc., electrons in any atom must always contribute the same amount to the weight of the atom whether its radius be large or small. Having received this suggestion from the theory, I have endeavored to ascertain whether it might not be possible to find out, from the known atomic weights of the different kinds of atoms, what the probable combinations of rings in such atoms are. The result of this has been more successful than I had reason to hope, knowing the very great irregularities that atomic weights exhibit. In the light of the theory it is possible to write down the approximate weights of any ring of electrons. I say approximate because it is not supposed that the speed is absolutely independent of the radius of the ring, but only so to a first approximation. Taking the speeds as strictly proportional to the number of electrons in the ring, the theory gives the weights of the rings as the squares of the number of electrons per ring, as the numbers, 1, 4, 9, 16, 25, for rings of 1, 2, 3, 4 and 5. Taking hydrogen as a ring of two and atomic weight 1.008, we get the numbers 2.268, 4.032, 6.300, and 9.072 as the weights of rings of 3, 4, 5 and 6 electrons. These are the strictly proportional figures, but I have found by trial that, if the following figures, differing very slightly from the above, are used, namely for a ring of two 1.008, three 2.269, four 3.99975, five 6.2898, and six 9.137, it is possible to get the atomic weights of all the elements from hydrogen to uranium within the probable error of experimental measurement in a large majority of cases. For most of the elements only the first three figures have to be used, corresponding to rings of 2, 3 and 4 electrons. Only a few elements require rings of five, namely the halogens, *Cl*, *Br*, and *I*, and the elements selenium and tellurium. The element iron is the only one based upon rings of six, with the possible exception of glucinum. In other words most of the atomic weights have been accurately obtained by the use of but three numbers, rings of 2, 3 and 4. Of the 70 elements calculated (the rare earths having been omitted) 52 of them fall very near to or within the experimental error of the chemist in measuring the weight, while 18 fall outside

of this accuracy. Of these 18, however, the weights of 15 of them come nearer than one part in 1000 to the measured weight, and most of them considerably nearer. Only three of these exceed a difference of one part in 1000. These are *L i*, 7.3 parts in 1000, *K* 1.2 parts, and *Y t* 2.26 parts. The largest difference by considerable margin is in the case of *L i*, which, however, is less than 1 per cent.

The system of rings as built up in this way seems to be based upon rings of four electrons, the number of rings of four increasing steadily with increasing atomic weight, the number of rings of two and of three being few. The cases of iron and the halogens are most interesting, as being built upon a different foundation. Rings of four will not fit these elements.

I would not give you an account of this matter here, were it not for the fact that the weights come out in this way remarkably close when based upon three numbers for the most part, and that these numbers agree so closely with the numbers arrived at by the theory above outlined.

XIII. The Number of Electrons per Atom According to the Above Satisfies Both Those Who Have Thought That the Number is Approximately Equal to the Atomic Number, and Those Who Have Taken it as the Same as the Atomic Weight

There are a few important matters which have been passed over without notice, that may now be mentioned. It has been an object among physicists for some time to discover just how many electrons the different kinds of atoms contain. This table of the elements made in the way just mentioned gives the number of electrons for each atom. Many have come to the conclusion that the number of electrons must be approximately equal to the atomic number, which is roughly one half the atomic weight. Others on different grounds have made the number approximately equal to the atomic weight. This table makes the number approximately the same as the atomic weight, but it will be observed that hydrogen has two and not a single electron. So the table satisfies both views of the matter, while it makes the number nearly the same as the atomic weight, the ratio of the number in an atom to the number in hydrogen is one half the atomic weight.

XIV. The Number of Electrons in the Hydrogen Atom

You have a right to be surprised that any question can be raised at this time as to the number of electrons in hydrogen. I can find, however, no experimental observation to prove there is but a single electron, and it seems that this view of the matter has been adopted along with the Bohr theory, which requires the single electron.

A few remarks upon this matter seem called for. If the velocities of electrons in rings are regulated as above described through the action of the tangential forces due to the other electrons in the ring upon the one according to electromagnetic theory, then we are deprived of this means of regulation when there is one isolated electron only. We do not have in such a system the perfectly symmetrical dynamic balance that obtains with two electrons.

Then, again, our present view of the matter does not neglect the radiation and loss of energy from the atoms. In electromagnetic theory the relative amounts of loss of energy through radiation for rings of 1, 2, 3, etc., using the speeds as above determined, diminishes very rapidly as the number in the ring increases. The loss from a ring of two is about 4000 times less than from the single electron, and from the ring of three about 40 million times less, and from four nearly a million million times less. For this reason it seems reasonable to suppose that the single isolated electron does not exist in the atoms. I shall not take the time here to answer the obvious objections to admitting loss of energy by radiation on account of the quantum theory, but may assure you that they can be met satisfactorily.

XI. The Order of Magnitude of the Orbits of the Electrons in Atoms

Another matter, which has been passed over relates to the order of magnitude of the orbits of the electrons. There are a number of things that have a very evident bearing upon this question. One of the things we know now with precision is the distance between the centers of the atoms in certain crystals. These distances in different crystals vary from perhaps 10^{-8} cm. up to 4 or 5 or possibly 6 times as much, and we may think of the order of magnitude as roughly 10^{-8} cm. Now, if the radii or the orbits of electrons in any of the atoms in the crystal approach close to the same order of magnitude, the electrons must necessarily approach each other much nearer than they

are from the nucleus to which they belong. Unless we are to assume that such electrons have no mutual influence upon each other, which seems uncalled for, there must occur in crystals an enormous perturbation with an ensuing radiation of energy. This could not possibly be a stable condition. Our exact knowledge of crystals alone ought to be considered a direct proof that the order of magnitude of the orbits of the electrons is much smaller than 10^{-8} cm.

Again, the kinetic theory of gases has been cited to show the order of magnitude of the radii. This theory has established the fact that the centers of the atoms in a gas approach each other on the average to within about 10^{-8} cm. before being deflected. If the orbits of the electrons were of this order too, they must at times come into very close proximity or even collision, and the result would be that some of the electrons would be separated from the nucleus, thus ionizing the gas under ordinary conditions. This does not occur. We may, I think, regard the kinetic theory as another direct proof that the orbits must be of a much smaller order. These matters, when taken in connection with the fact that the radii come out between 10^{-10} and 10^{-9} cm., when the forces due to the motion of the electrons is included, which was omitted from the Bohr theory, and with the fact that these radii agree with the values indicated by an application of the theory to crystals, do not leave much doubt as to the true sizes of the orbits of the electrons.

I can picture the thought that is probably occurring to many of you, while listening to this description of a difference of opinion affecting the radii of the orbits between ten and a hundred times. In what condition would astronomers find themselves so long as they were in doubt about the value of the radius of the earth's orbit by a factor of some ten or hundred times? Evidently, until this matter is determined with some precision, all attempts to place atomic theory upon a firm mechanical basis cannot be very successful. It will have to be acknowledged, however, that the physicist does not find any such single simple law applying to atoms at close range as governs the motions of the heavenly bodies, and the reasons why we are not further along are not difficult to understand.

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NO-LOAD CONDITIONS OF SINGLE-PHASE INDUCTION MOTORS AND PHASE CONVERTERS

BY R. E. HELLMUND

ABSTRACT OF PAPER

This paper shows methods and derives formulas for the determination of the fields, the stator and rotor magnetizing currents, and the tertiary voltages for phase converters and single-phase induction motors at no-load. Previous publications on this subject, including text books, are usually rather vague and incomplete, especially with regard to the secondary magnetizing currents and the field forms. Furthermore, numerous conflicting statements are found in previous literature, thus leaving the subject, as a whole, in a rather confusing condition. This paper treats a large number of different cases along similar lines, thereby coordinating and explaining many phenomena previously observed, and it should, therefore, form a desirable basis for further investigations and discussion of this subject matter.

The treatment of all cases is rather uniformly based on the following fundamental considerations. The sum of all e.m.fs. must be zero in both the primary and secondary circuits. With the impressed primary e.m.f. known, this leads to definite conditions governing the primary counter e.m.fs. The same law applied to the secondary circuits gives the condition that the induced voltages must be equal and opposite to the ohmic drops. Having thus certain laws governing the voltages to be induced in the windings, we have at once certain laws governing the fluxes for inducing these voltages. In most cases, it is then found, that only a single definite local distribution of the resultant field satisfies both the conditions for the primary and secondary windings simultaneously; having thus established the required resultant field distribution, we have at once laws for the required resultant distribution of ampere turns around the circumference to bring about such field distributions. Whenever certain portions of the circumference have conductors of either the primary winding or secondary winding alone, the resultant ampere turns found represent at once the ampere turns for the single winding located at this portion. With this fact known, a number of facts regarding the currents can be determined. Whenever both primary and secondary turns coincide at the same portion of the circumference, certain problems arise in determining the distribution of the resultant ampere turns between the two windings. A number of different considerations are used for the various cases to assist in the solution of these problems; all these considerations are, however, based on simple facts.

In order to demonstrate the method by means of the simplest mathematics, two cases of small practical application are given first merely in order to separate the fundamentals from a rather

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large amount of mathematics which, while necessary, in connection with the more practical cases, are of little value in connection with the understanding of the fundamental principles. Starting out from these simple cases, the influence of various factors are taken up in the following cases, one at a time, because a simultaneous consideration of all of them make a clear understanding practically impossible.

The paper is arranged so that it can be read to good advantage without going through those mathematical parts marked by vertical rules.

By reading the conclusions at the end of the paper, a fair idea of the principal points brought out in the paper can be obtained.

Introduction

THE EXACT nature of the fields and magnetizing currents of single-phase induction motors, especially of the currents flowing in the rotor, have been the subject of a good deal of speculation in the past. The introduction of the phase converter as a commercial machine has given additional interest to these problems, and has furthermore introduced a number of new problems, as for instance, the determination of the output voltage. The following studies of the no-load conditions in these machines, which form the necessary basis for further studies of the load conditions should, therefore, be of interest to students and designers of such machines.

The fundamental laws and basic considerations used in the paper are very simple and should be easily understood. Also, the mathematics are relatively simple, involving, with very few exceptions, nothing but the solution of several equations with several unknown quantities; the integrals used in a few places are of the simplest kind. Nevertheless the derivations involve by necessity a rather large number of formulas, which will be of interest only to a limited number of readers. An attempt has, therefore, been made to write the paper, so that it can be read to good advantage, without following through the mathematical portions, marked by vertical rules.

The results, given graphically in a large number of figures, and the conclusions reached, should be of general interest. Some of the final conclusions and formulas will enable the designing engineer to predetermine machine performance more accurately than was possible with the previous methods, most of which are based on more or less incorrect assumptions.

Wherever a correct and complete mathematical solution has not been attempted, because it involves an impractical amount of work, the considerations have been carried far enough to

indicate plainly to the student and designer how the most favorable design can be obtained and how bad combinations can be avoided.

A number of simple theoretical cases are given first, because it is believed that the demonstration of the methods employed in this paper on such simple cases will be of assistance in the understanding of the more general solutions of the problems given later on.

CASE NO. I

Single Primary Coil, Single-Phase Secondary

The simplest type of a phase converter is shown with its rotor in different positions in Figs. 1A to 1E. It has a single concen-

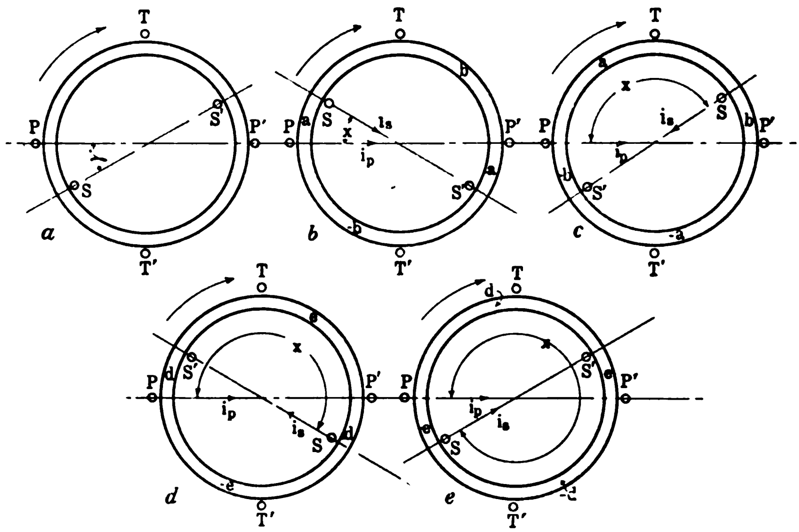

FIG. 1

trated primary coil $P P'$, a single concentrated secondary or rotor coil $S S'$ and a single concentrated output or tertiary coil $T T'$, located on the stator 90 electrical space degrees shifted against the stator coil $P P'$.

The first fundamental condition, which must be fulfilled in a machine of this kind, is that *within every closed circuit, the sum of all counter e. m. f's. must at any moment be equal and opposite to the impressed e. m. f.*

Applying this law to the primary coil $P P'$, we know, therefore, that if we impress a sinusoidal voltage wave with instantaneous voltage values

$$-e_p = -E \sin \alpha$$

that the counter e. m. f's. in this winding must be always opposite in direction, but of the same numerical value, namely,

$$e_p = E \sin \alpha \tag{1}$$

where E is the maximum crest value of the voltage and α the time angle.

The counter e. m. fs. consist of ohmic drops and electromagnetically induced voltages.

The ohmic drops at no-load are usually very small in a-c. machines relative to the inductive voltage and may, therefore, for the present be neglected.

The inductive voltage is always proportional to the rate of change of the total flux interlinking with the coil $P P'$. Since the voltage to be induced is definitely given by equation (**1**), the flux values within the coil are also definitely given by ***the second fundamental conditions, that the rate of change of the flux within a coil must be at any moment proportional to the inductive e. m. f. to be induced.***

This leads to the well known formulas

$$\varphi = \frac{E\,10^8}{2\,\pi\,f\,n_p} = \frac{0.45\,e\,10^8}{f\,c_p} \tag{2}$$

and

$$\varphi_i = \varphi \cos \alpha = \frac{E\,10^8}{2\,\pi\,f\,n_p} \cos \alpha \tag{3}$$

wherein

e = effective primary voltage = $0.707\,E$
φ = maximum flux interlinking with coil $P P'$
φ_i = instantaneous flux interlinking with coil $P P'$
f = frequency (cycles per second)
c_p = number of primary conductors
n_p = number of turns in primary coil.

These are the only conditions governing the flux in the primary coil. It is altogether immaterial, with regard to the primary, whether these conditions are fulfilled by a stationary flux fluctuating in size, by a single rotating flux of sinusoidal space distribution, or by a number of fluxes rotating in the same or in opposite directions, or even by a combination of fluctuating and rotating fluxes. It is also immaterial with regard to the primary coil how these fluxes are locally distributed within the coil, whether these fluxes are set up by currents in the primary or the secondary coil, whether by direct currents or alternating cur-

rents, or a combination of such currents, as long as the above conditions are fulfilled.

If the secondary and tertiary coils are open circuited and inactive, so that none but the primary coil can furnish magnetomotive forces, the entire magnetization must naturally be furnished by the primary coil $P P'$. It is further evident in this case that the flux distribution and magnetic densities within the coil are solely governed by the relative magnetic reluctances of the different paths.

Under the customary assumption of uniform reluctance and neglecting for the present the relatively small magnetic leakage fluxes, the above leads to the well known relations:

The instantaneous gap density is

$$B_i = \frac{2\,\varphi_i}{D\,\pi\,l} = \frac{\varphi_i}{\pi} K \qquad (4)$$

if
$$K = \frac{2}{D\,l} \text{ and}$$

if the average air gap diameter $= D$

Width of core $= l$

The instantaneous current value, in the primary coil, is

$$i_p = \frac{B_i}{n_p}\,\frac{l}{K_l} = \frac{\varphi_i\,K}{\pi\,K_l\,n_p} \qquad (5)$$

where K_l is a constant.

From this, the crest value of the current is

$$I_p = \frac{\varphi}{\pi}\,\frac{K}{K_l\,n_p} \qquad (5\text{ A})$$

Let us assume now that the coil $S S'$ is short-circuited and revolved at synchronous speed by some external means.

By applying the first fundamental condition given above to this secondary coil, we know that in so far as this coil is short-circuited and has no external voltage impressed, we must have a resultant counter e.m.f. of zero induced within the coil. If there is any current flowing within the coil, it will cause an ohmic drop voltage. Therefore, in order to get a resultant of zero we must have an inductive voltage induced internally, which is equal and opposite to this ohmic drop voltage. The resistance of the coil $S S'$ is usually very small so that the ohmic drop is very small and with it also the necessary inductive

voltage, as long as the secondary currents are not too large. Under the majority of conditions the required rate of change of the flux interlinking with the coil $S S'$ is, therefore, so small as to be negligible, as compared with that required in the primary coil. We are, thus, justified to assume at present for the sake of simplicity, that the flux within the secondary coil remains practically constant. This is, however, theoretically correct only with zero resistance in the secondary.

It is again indifferent with regard to the secondary coil how this condition of practically constant flux within the coil is maintained. We know, however, that if a flux has once been established by some means or other, within the coil, such flux will somehow be maintained practically constant. If the magnetomotive force which has established the flux disappears, or if the secondary coil is moved away from its influence, the flux within the coil will tend to diminish. Any slight decrease of flux will, however, at once induce voltages in the coil which, in turn, cause currents to flow maintaining the flux practically at its original value, if the ohmic drops are zero, or at least negligible.

Let us refer now to Fig. 1A and assume that it happens to represent the rotor position at the time angle $\alpha = 0$, with an angle γ between the coil $P P'$ and $S S'$ as shown. Assuming further synchronous speed, we know that the time $\alpha = \gamma$ will have elapsed, before the secondary coil has moved an angle γ and coincides with the primary coil. Now we know from formula (**1**) that the flux interlinking with the primary coil at the time $\alpha = \gamma$ must be

$$\varphi_{i\gamma} = \varphi \cos \gamma \tag{6}$$

If we neglect the leakage between the coils $P P'$ and $S S'$ this represents also the flux in the secondary coil at this time.

Since the flux in $S S'$ is constant, we know, therefore, that this constant flux of coil $S S'$, which rotates with the coil at synchronous speed must be

$$\varphi_s = \varphi \cos \gamma \tag{7}$$

Having now an equation for both the total flux φ_i in the primary and the total flux φ_s in the secondary coil, we can easily determine how the fluxes around the air gap must be distributed at any time to always satisfy both the equations (**1**) and (**7**) for φ_i and φ_s respectively.

Let us consider for instance a secondary position as shown

in Fig. 1B, with an angle x between $P\,P'$ and $S\,S'$. The time angle corresponding to this position is

$$\alpha = x + \gamma \text{ therefore } x = \alpha - \gamma \tag{8}$$

By reference to Fig. 1B, it is further at once evident that the flux between P and P', that is the primary flux φ_i must be the sum of the fluxes φ_a between P and S and the flux φ_b between S and P'; similarly, we see that the flux between S and S' that is the secondary flux φ_s must be the sum of the flux φ_b between S and P' and the flux φ_a' between P' and S'. Since φ_a' is evidently equal to $-\varphi_a$, we have only two unknown quantities which can at once be found from the two conditions just stated. With the fluxes for the different air-gap portions known and the angles for which they apply the densities can be easily found.

For the time $\alpha = \gamma$ to $\alpha = \gamma + \pi$ which it takes the conductor S to travel from P to P', we can, therefore, write the following equations

$$\varphi_i = \varphi_a + \varphi_b \tag{9}$$

$$\varphi_s = -\varphi_a + \varphi_b \tag{10}$$

It follows by addition and subtraction of (9) and (10)

$$\varphi_a = \frac{\varphi_i - \varphi_s}{2}$$

$$= (\cos\alpha - \cos\gamma)\,\frac{\varphi}{2} \tag{11}$$

$$\varphi_b = \frac{\varphi_i + \varphi_s}{2}$$

$$= (\cos\alpha + \cos\gamma)\,\frac{\varphi}{2} \tag{12}$$

The densities over the distances a and b of Fig. 1B, are, therefore,

$$B_a = \frac{\varphi_a}{x}\,K = \frac{\varphi_i - \varphi_s}{2\,x}\,K$$

$$= \frac{\cos\alpha - \cos\gamma}{x}\,\frac{K}{2}\,\varphi \tag{13}$$

$$B_b = \frac{\varphi_b}{\pi - x}\,K = \frac{\varphi_i + \varphi_s}{2\,(\pi - x)}\,K$$

$$= \frac{\cos\alpha + \cos\gamma}{\pi - x}\,\frac{K}{2}\,\varphi \tag{14}$$

Similarly, we find for the time

$$\alpha = \gamma + \pi \text{ to } \alpha = \gamma + 2\pi$$

in connection with Fig. 1D.

$$B_d = \frac{K}{2} \varphi \frac{\cos \alpha - \cos \gamma}{x - \pi} \quad (15)$$

$$B_e = \frac{K}{2} \varphi \frac{\cos \alpha + \cos \gamma}{2\pi - x} \quad (16)$$

The field densities thus obtained are shown in full lines in Fig. 2, with regard to their local distribution over the air gap

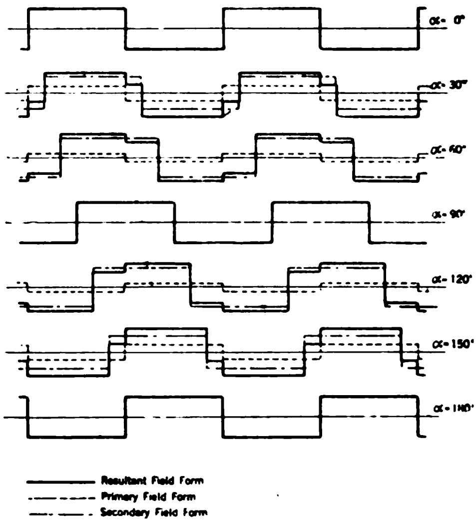

FIG. 2

circumference for a number of values of α as indicated, and under the assumption of $\gamma = 0$, which means that the secondary and primary coils are assumed to coincide at the time angle $\alpha = 0$, that is, when the primary flux has its maximum value. The areas enclosed by the full lines represent the total fluxes, as they must exist to fulfill the two fundamental conditions so far stated, for both the primary and secondary coil.

As previously pointed out, the two conditions of equilibrium could be fulfilled in a number of different ways for each of the windings individually. Since our equations, taking the two windings into account, simultaneously, give only a single solution, however, Fig. 2 represents the only field condition possible under the assumptions made.

For different values of γ somewhat different results will be obtained but usually it will be found as in Fig. 2 that the resultant field travels around with the rotor, *i. e.*, we have a rotating field; it will also be noticed that the distribution of the field varies.

As a matter of convenience in theoretical considerations, it is, of course, always possible to substitute a number of component fields for those obtained from the calculations, but the resultant of such field must always conform to our equations.

The determination of the currents flowing in the two windings must be based on ***a third fundamental condition***, namely, ***that the sum of all ampere turns acting upon a certain part of the gap circumference must be proportional to the magnetic density in such part***, making the usual assumption of uniform magnetic reluctance.

Referring, for instance, again to Fig. 1B, in which certain current directions have been arbitrarily assumed and indicated by arrows, it is at once evident that the density B_a between P and S, for instance, must be set proportional to the difference between the ampere turns in $P\,P'$ and those in $S\,S'$. Determining similar relation for other portions, we obtain at least two equations with the two unknown current values i_p and i_s, which follow directly from the solution of these equations.

If the secondary coil $S\,S'$ with the turns n_s carries the current i_s in a direction as marked in Fig. 1B, we find the following relations between the currents and densities.

$$B_a = K_l\,(i_p\,n_p - i_s\,n_s) \quad \textbf{(17)}$$

$$B_b = K_l\,(i_p\,n_p + i_s\,n_s) \quad \textbf{(18)}$$

By additions and subtraction of **(17)** and **(18)**, we get

$$i_p = \frac{B_a + B_b}{2\,K_l\,n_p} = \frac{K\,\varphi}{4\,K_l\,n_p}\left(\frac{\cos\alpha - \cos\gamma}{x} + \frac{\cos\alpha + \cos\gamma}{\pi - x}\right) \quad \textbf{(20)}$$

$$i_s = \frac{B_b - B_a}{2\,K_l\,n_s} = \frac{K\,\varphi}{4\,K_l\,n_p}\left(\frac{\cos\alpha + \cos\gamma}{\pi - x} - \frac{\cos\alpha - \cos\gamma}{x}\right) \quad \textbf{(21)}$$

Similarly, we find for the time $\alpha = \gamma + \pi$ to $\alpha = \gamma + 2\pi$ in connection with Fig. 1D.

$$i_p = \frac{K\varphi}{4 K_l n_p}\left(\frac{\cos\alpha - \cos\gamma}{x - \pi} + \frac{\cos\alpha + \cos\gamma}{2\pi - x}\right) \tag{22}$$

$$i_s = \frac{K\varphi}{4 K_l n_s}\left(\frac{\cos\alpha - \cos\gamma}{x - \pi} - \frac{\cos\alpha + \cos\gamma}{2\pi - x}\right) \tag{23}$$

Fig. 3 shows in light lines the values for i_p (Curve P) and i_s (Curve S) as a function of the time angle α and as found from (**20**) to (**23**), again for the assumption $\gamma = 0$.

These light curves represent the single and only solution of our equations at any time except at the instant when the secondary and primary coils coincide. At these instances, as for example at the time $\alpha = 0$ with $\gamma = 0$, the above third fundamental condition must be fulfilled as much as at any other time. We have, however, at this instant only the flux $\varphi_a = \varphi_i$, the angle x being 0. Our condition is, therefore, given by

$$B_b = K_l\,(i_p\,n_p + i_s\,n_s)$$

that is the same as in equation (**18**), but there being no value for B_a, we have only one equation with the two unknown quantities.

The single equation known for $\alpha = 0$, etc., is satisfied with any values for i_p and i_s, as long as

$$i_p\,n_p + i_s\,n_s = \frac{B_a}{K} = \frac{\varphi}{\pi}\;\frac{K}{K_l}$$

or assuming $n_p = n_s$

$$i_p + i_s = \frac{\varphi}{n_p\,\pi}\;\frac{K}{K_l} = i_x \tag{24}$$

This simply means that from our third condition nothing but the sum i_x of i_p and i_s is known, while it is possible to fulfill equation (**24**) for any value of i_s between $-\infty$ and $+\infty$ by assuming i_p to correspond.

The following consideration makes, however, a determination of i_s for the time $\alpha = 0$, $\alpha = \pi$ etc., possible. Assume coil $S\,S'$ coincides with $P\,P'$ at the time $\alpha = 0$ with $\gamma = 0$, *i. e.*, when $\varphi_s = \varphi$. For any other position, the currents in $S\,S'$ tend to maintain this flux, as previously pointed out, by furnishing whatever magnetizing current is required to do so, in addition

to the primary current. In order to cause such magnetizing current to flow with even the smallest secondary resistance, an inductive voltage induced by slight changes of the flux φ_s is required. While it was permissible to neglect these small changes in our previous calculation of densities and currents, we must not overlook that a small change in the flux is necessary to make i_s flow between the times $\alpha = 0$ and $\alpha = \pi$. We further know that while $S\,S'$ travels from $x = 0$ to $x = \pi$ the primary flux has changed from φ to $-\varphi$ that is, it has reversed its direction with regard to $P\,P'$. Its direction with regard to SS' which has traveled 180 deg. in the meantime is, however, the same for both $\alpha = 0$ and $\alpha = \pi$. In other words we know that while φ_s undergoes slight variations, it must periodically resume in intervals of π the same value, which is φ in our present case. This, in turn, means that any flux decrease in coil $S\,S'$ must be followed by an increase, further, that for a full time interval π, the sum of all increases must equal the sum of all decreases. If, therefore, $d\,\varphi_s$ represents the infinitely small flux change during a time dt, we know that

$$\Sigma\, d\,\varphi_s = 0$$

Since the rate of change of the flux φ_s determines the voltage, we have $\frac{d\,\varphi_s}{dt} = e_s = i_s\, r_s$ or $d\,\varphi_s = i_s\, r_s\, dt$ where $e_s =$ the voltage induced in $S\,S'$ and r_s the resistance. We have further

$$\Sigma\, d\,\varphi_s = r_s\, \Sigma\, i_s\, dt = 0 \tag{30}$$

between the limits 0 and π.

The value $\Sigma\, i_s\, dt$ represents the area included by the secondary current curve over the time 0 to π, the resultant of which must, therefore, be zero, if r has a value different from 0.

From this, we can directly derive our *fourth fundamental condition*, namely, *that the voltages induced and, therefore, the currents flowing in the secondary coil must have an average value of zero, over each complete time period of* π.

In other words this means that the areas of a curve, including all positive current values must be equal to the area of a curve, including all negative current values.

An inspection of curve S, in Fig. 3, reveals that all current values of i_s between $\alpha = 0$ and $\alpha = \pi$ are positive, and it is, therefore, at once evident that the current can be negative only for infinitely short time intervals at $\alpha = 0$, $\alpha = \pi$ etc. This means that the height of the negative current area must

be $-\infty$, in order to give with an infinitely small basis an area equal to the corresponding positive current area.

The value of i_s for $\alpha = 0$, etc., having been thus determined, it follows at once from (**24**) that

$$i_p = \infty + \frac{\varphi}{n_p \pi} \frac{K}{K_l} = \infty$$

The theoretical infinite current values are indicated by heavy vertical lines in Fig. 3. The conclusion to be drawn from the

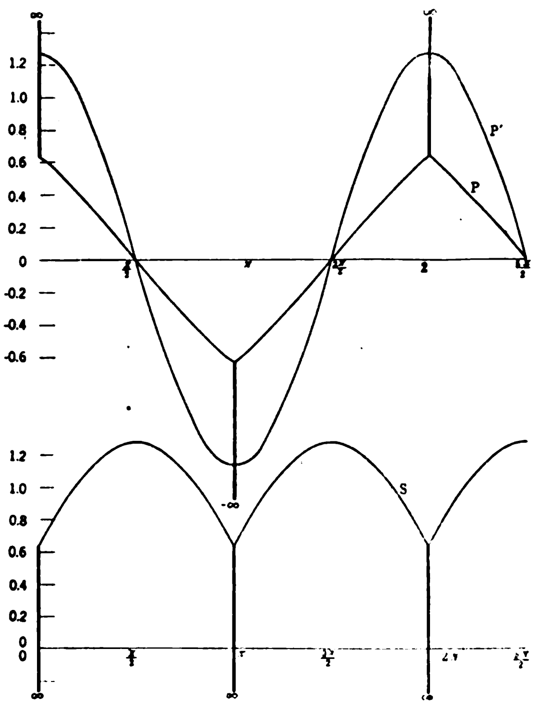

FIG. 3

completed current curves is that the primary currents are of line frequency with very marked odd higher harmonics, while the secondary currents are of double line frequency with very marked higher harmonics; the fact that the positive and negative wave shapes are materially different indicates the rather unusual existence of marked even harmonics in the secondary currents.

Fig. 3 also shows in a curve P' the value of i_p as obtained from (**5**) for the open circuited secondary. It will be seen that

the effective i_p of curve P, without the infinitely high extension would be even smaller than that of curve P', which we know to be in contradiction to the facts. This is additional evidence for the necessity of a sudden change of the currents for $\alpha = 0$ and $\alpha = \pi$.

In line with the above, Fig. 2 shows in dotted lines the field components supplied by the stator and the rotor for all cases except for $\alpha = 0$ and $\alpha = \pi$ in which cases these values are ∞; in case of $\alpha = \frac{\pi}{2}$ the dotted lines do not appear because the field induced in the primary is zero, and that induced by the secondary coincides with the total field.

For most other values of γ, similar conditions are obtained, but the coinciding of the coils and, therefore, the infinite current values occur at different values for α.

While the current curves derived so far are correct under the assumption made, attention may already be briefly directed towards a number of facts, which have marked modifying effect in actual machines.

In practise, it is, of course, impossible to concentrate the effect of the coil conductors into a point, and, therefore, the passing of the secondary and primary coils is not actually infinitely short. Consequently, we obtain in the secondary, even though the coils are concentrated as much as practicable, certain limited but rather large current values for a rather short time, in place of the infinite negative values for an infinitely short time. Similarly, the additions to the calculated primary current wave are not infin tely large, but will appear as rather sharp corners of limited height extending over a very brief period of time.

Another equally important feature, which makes the existence of infinite current values in actual practise impossible, is the fact that any machine has magnetic leakage fluxes. These fluxes no matter how small they may be will induce very appreciable voltages affecting the working conditions to a marked degree, if the rate of change in such fluxes is large; the latter condition naturally prevails if the currents setting up the leakage fluxes suddenly tend to assume infinite values, as in our case.

While, for these reasons, the previous current curves, as well as some of those given later, do not picture the actual conditions correctly, they are nevertheless very instructive insofar as they indicate the strong tendency owards higher harmonics and

secondary phenomena caused thereby. This will be discussed more in detail later on.

The fluxes interlinking with the tertiary phase converter coil $T\,T'$ can easily be determined, since the densities at all portions of the circumference are known, if we neglect again the leakage fluxes. With the fluxes known, the induced tertiary voltage follow directly by finding the rate of change of the tertiary flux $\frac{d\,\varphi_t}{dt}$.

We have

For the time $\alpha = \gamma$ to $\alpha = \gamma + \frac{\pi}{2}$ (Fig. 1B)

$$\varphi_t = B_b \frac{\pi}{2} - B_a\,x - B_b\left(\frac{\pi}{2} - x\right)$$

$$= (B_b - B_a)\,\frac{x}{K} \qquad (25)$$

For the time $\alpha = \gamma + \frac{\pi}{2}$ to $\alpha = \gamma + \pi$ (Fig. 1c)

$$\varphi_t = B_a\left(x - \frac{\pi}{2}\right) + B_b\,(\pi - x) - B_a\frac{\pi}{2}$$

$$= \frac{(\pi - x)}{K}\,(B_b - B_a) \qquad (26)$$

For the time $\alpha = \gamma + \pi$ to $\alpha = \gamma + \frac{3}{2}\,\pi$ (Fig. 1D)

$$\varphi_t = B_e\frac{\pi}{2} - B_d\,(x - \pi) - B_e\left(\frac{3}{2}\,\pi - x\right)$$

$$= \frac{(\pi - x)}{K}\,(B_d - B_e) \qquad (27)$$

For the time $\alpha = \gamma + \frac{3}{2}\,\pi$ to $\alpha = \gamma + 2\,\pi$ (Fig. 1E)

$$\varphi_t = B_d\left(x - \frac{3}{2}\,\pi\right) + B_e\,(2\,\pi - x) - B_d\frac{\pi}{2}$$

$$= \frac{(2\,\pi - x)}{K}\,(B_e - B_d) \qquad (28)$$

The voltage of the tertiary coil can be found by finding the value $\frac{d\,\varphi_t}{dt} = e_t$ from these equations, after

the previously found values for B_a and B_d in terms of α have been introduced. Thus we obtain for the time

$$\alpha = \gamma \text{ to } \alpha = \gamma + \frac{\pi}{2}$$

$$e_t = \frac{\varphi}{2}\left[\frac{\pi}{(\pi - \alpha + \gamma)^2}(\cos\alpha + \cos\gamma) + \left(1 - \frac{\alpha - \gamma}{\pi - \alpha + \gamma}\right)\sin\alpha\right] \quad (29)$$

etc.

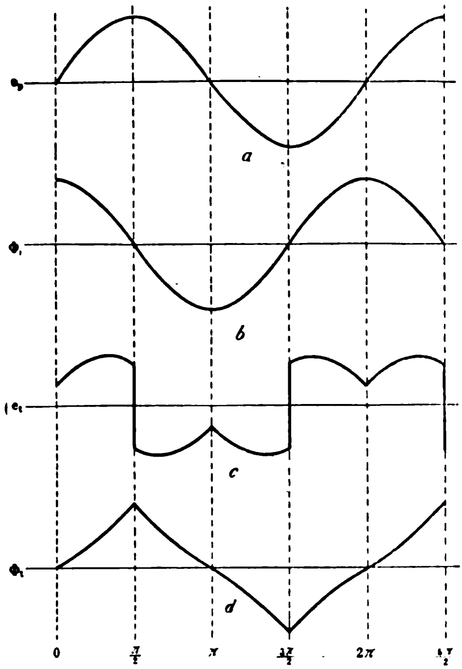

FIG. 4—$\gamma = 0$

Fig. 4 shows the time curves of the primary voltage of the coil $P\,P'$ and the flux φ_i interlinking with this coil as found from **(1)** and **(3)**, further the flux φ_t interlinking with the tertiary coil $T\,T'$ and the voltage induced in this coil as found from **(25)**, **(26)**, **(27)**, **(28)** and **(29)**.

It will be noted that although the primary voltage and flux follow a sine law, the tertiary flux and voltage are far from such law. The tertiary maximum flux value is the same as that of the primary, but both the average and effective values are lower in case of the tertiary flux.

The case of Fig. 1 for $\gamma = \frac{\pi}{2}$, that is, the case in which coil $S\,S'$ and $P\,P'$ coincide at the time $\alpha = \frac{\pi}{2}$ when the primary flux is 0, is of little interest in connection with the phase-converting problems. It is interesting, however, insofar as we obtain in this case an appreciable secondary voltage of double frequency. The fluxes and voltages for this case are shown in

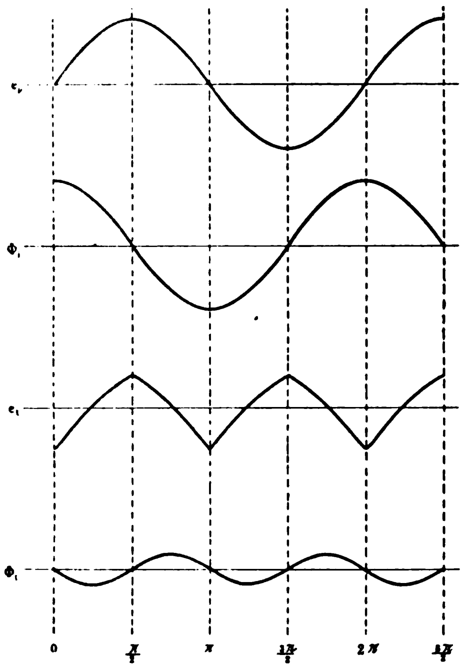

FIG. 5—$\gamma = \frac{\pi}{2}$

Fig. 5. The results obtained are somewhat surprising, since it would appear from a casual consideration that insofar as the resultant secondary flux

$$\varphi_s = \varphi \cos \gamma = \varphi \cos \frac{\pi}{2} = 0$$

is zero, that φ_t should be zero.

Closer investigation shows, however, that while φ_s is zero, as a whole, it is at times the resultant of two opposing fluxes, which add up to zero inside the coil $S\,S'$, but give certain positive and

negative values inside of $T\,T'$ as shown in Fig. 5D. While these fluxes are relatively small, they are of double frequency and, therefore, induce an appreciable voltage in $T\,T'$. We have, therefore, for $\gamma = \frac{\pi}{2}$ a frequency changer instead of phase converter.

While a further study of these phenomena with relation to the resistances and leakage fields would be interesting it has been omitted since it is not related to the subject matter of this paper.

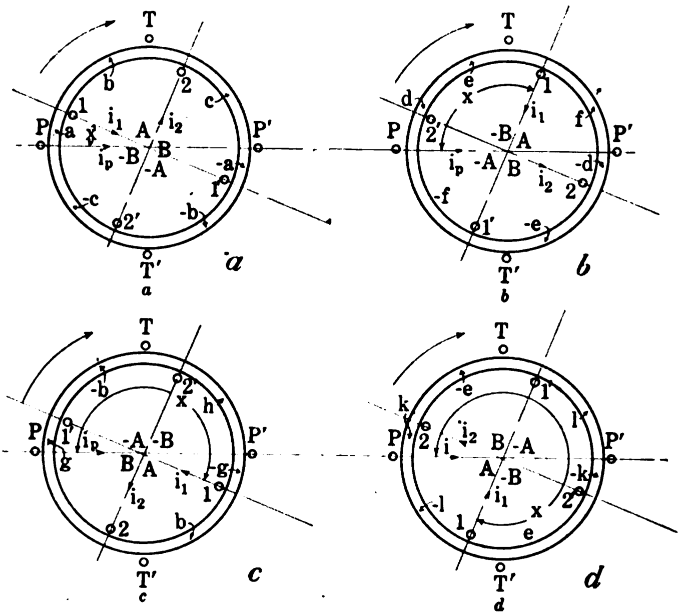

FIG. 6

CASE NO. 2.

Single Primary Coil, Two-Phase Secondary

Let us now consider a converter with a two-phase secondary with one coil per pole per phase, as shown in Fig. 6. Attached appendix gives the detail calculations carried through along the same lines as in the previous case.

The only difference in the calculations between this and the previous case is that two instead of one secondary coil has to be considered, which leads to three equations with three unknown quantities, instead of two.

Fig. 7 shows for $\gamma = 0$ the currents in the primary and in the two secondary coils. The calculation from the formulas gives again only positive currents for i_1, which for reasons previously

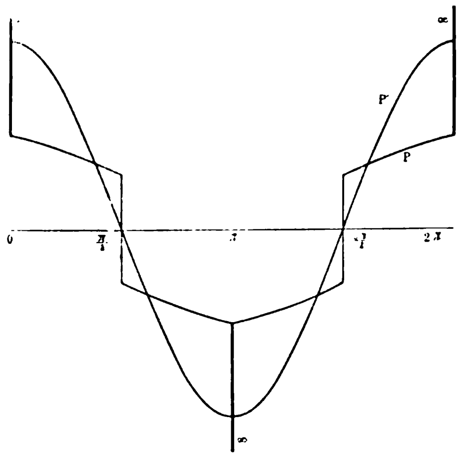

FIG. 7A

given, necessitates the infinite negative values, indicated by the heavy vertical lines, and the corresponding infinite positive values of i_p for $\alpha = 0$ and $\alpha = \pi$. The values found for i_2

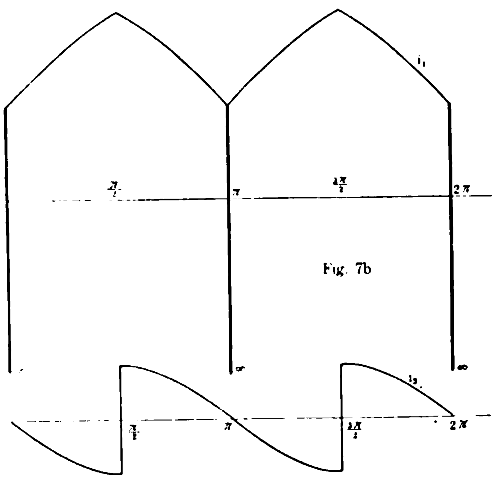

FIG. 7C

satisfy our fourth fundamental condition, without infinite **values.**

Fig. 8 shows the corresponding primary and tertiary **fluxes and** voltages.

Since we have now a polyphase rotor, the machine will be self-propelling like any single-phase induction motor. If the machine is asynchronous, the friction will cause a very small slip, so that even if the relation $\gamma = 0$ were originally established, the rotor will slip slightly behind synchronous speed, so that the value of γ changes gradually, but continuously. Therefore, other values than $\gamma = 0$ are of practical interest.

Fig. 9 has been worked out to give the currents for $\gamma = \frac{\pi}{4}$

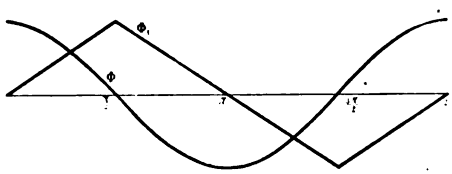

FIG. 8A

that is for the case, where the primary flux reaches a maximum, when the middle of a secondary tooth coincides with the primary coil. As will be seen both secondary currents have now infinite negative values.

Fig. 10 shows the corresponding primary and tertiary fluxes and voltages.

Fig. 11 shows the field forms for various values of α for $\gamma = 0$; while Fig. 12 covers the case of $\gamma = \frac{\pi}{4}$

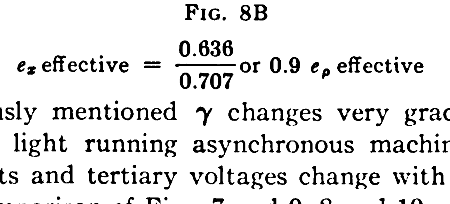

FIG. 8B

$$e_x \text{ effective} = \frac{0.636}{0.707} \text{ or } 0.9\, e_p \text{ effective}$$

As previously mentioned γ changes very gradually all the time with a light running asynchronous machine. Since the fields, currents and tertiary voltages change with γ, as will be seen by a comparison of Figs. 7 and 9, 8 and 10, and 11 and 12 respectively; this means that nearly everything in the machine undergoes a continuous change. Thus, the higher harmonics or current peaks of the primary change their location with regard to the fundamental wave. (Compare Figs. 7A and 9A); the cur-

rents in each secondary coil change materially in both size and shape, (Compare Figs. 7B and 9B, also 7C and 9C); also the tertiary voltages change their wave form materially (Compare Figs. 8B and 10B) as well as their peak values; similar conditions

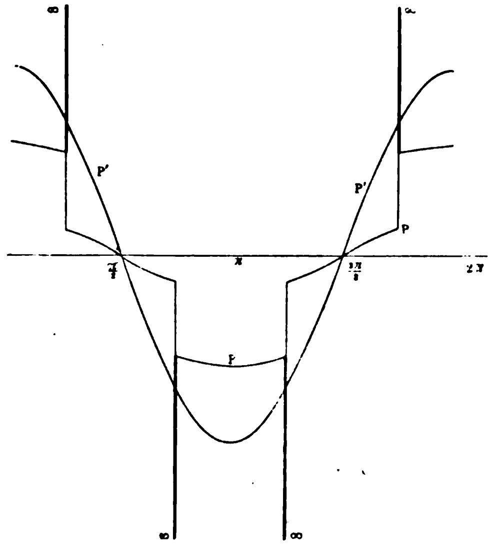

FIG. 9A

apply to the tertiary flux values (Compare Figs. 8A and 10A) interlinking with coil $T\ T'$.

The current curves show again general characteristics as in Case No. 1 with regard to fundamental frequency and higher harmonics.

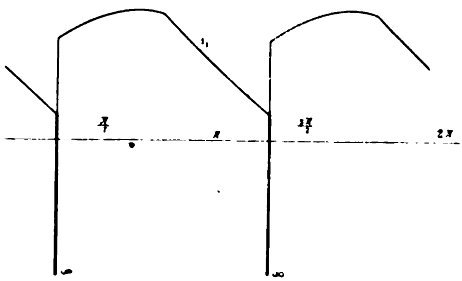

FIG. 9B

The local distribution of the resultant field changes continuously even with constant value of γ, as indicated in Fig. 11, but changes in the value of γ, cause further material changes. (Compare Figs. 11 and 12.) Among other things it will be noted

for instance that the total area for certain values of α is smaller in Fig. 12 than for similar values of α in Fig. 11. Figs. 11 and 12 show, however, in both cases that the resultant field rotates in the direction of the rotor. These figures also show in dotted

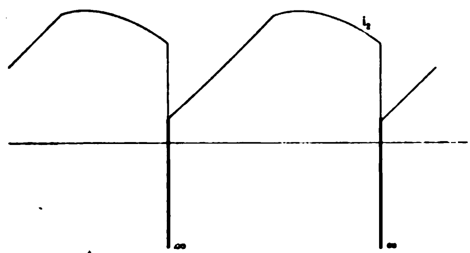

FIG. 9C

lines the fields as furnished by the primary and secondary coils alone.

The lines y y indicate the center of the resultant field and plainly show its travel from left to right; the center line of the

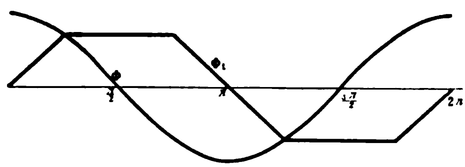

FIG. 10A

field induced by the primary currents is marked z z, and is of course, stationary; the center line of the fields induced by the secondary currents are marked x x, and it will be seen that they move in general in a direction opposite to that of the lines y y,

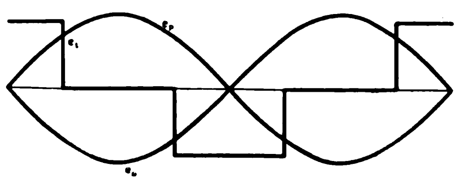

FIG. 10B

$$e_x \text{ effective} = \frac{0.636}{0.707} \text{ or } 0.9\ e_p \text{ eff.}$$

although their speed is very irregular and reverses for certain intervals of time.

In view of the irregular behavior of nearly everything in the motor, it is rather surprising that exact calculations show the effective value of the tertiary voltage to be unchanged with

changing γ namely always 90 per cent of the effective primary voltage, although as mentioned before, the wave shape of the tertiary voltage changes continuously with γ.

Case No. 3

Single Primary Coil, Polyphase Secondary

A case with single concentrated primary and tertiary coils in combination with a polyphase rotor winding with m rotor coils as shown in Fig. 13 may now be considered. The rotor position as shown is assumed to correspond to the time angle $\alpha = 0$.

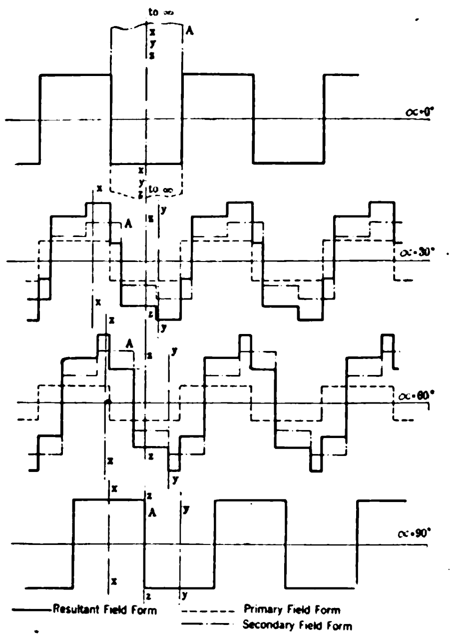

Fig. 11

By finding again, as in the previous cases, the time at which each secondary coil coincides with the primary and by determining the value of the primary flux at this time, we can easily find the constant total fluxes interlinking with each secondary coil.

The secondary coils pass coil $P\ P'$ as follows.

Coil 1	at the time	γ
" 2 "	" "	$\gamma - \beta$
" 3 "	" "	$\gamma - 2\beta$
" n "	" "	$\gamma - (n - 1)\beta$
etc.		

Consequently, the constant fluxes interlinking with these coils are

$$\begin{aligned} \varphi_1 &= \varphi \cos \gamma \\ \varphi_2 &= \varphi \cos (\gamma - \beta) \\ \varphi_n &= \varphi \cos [\gamma - (n-1)\beta] \\ \varphi_r &= \varphi \cos [\gamma - (r-1)\beta] \\ \varphi_{r+1} &= \varphi \cos (\gamma - r\beta) \\ &\text{etc.} \end{aligned} \tag{31}$$

We also have $\gamma = (r-1)\beta$ and $\beta = \dfrac{\pi}{m}$

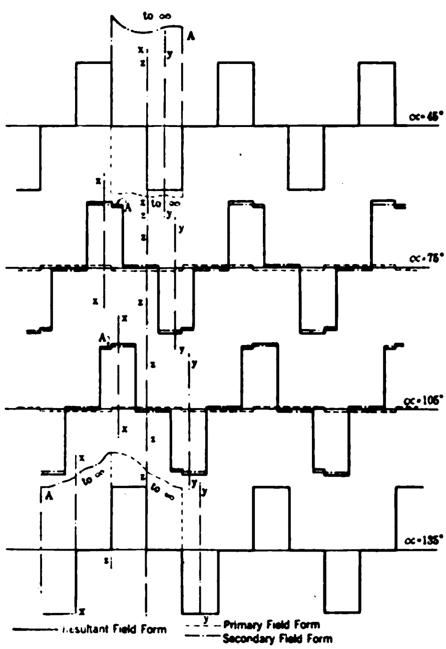

FIG. 12

The determination of the fluxes in the individual teeth and the densities, by the previous method of writing as many equations as there are tooth fluxes, would be, of course, very laborious in the present case with many secondary teeth. The calculations immediately following this prove, however, that the total flux of each secondary tooth can be found as one-half the difference of the total fluxes interlinking with the two adjacent coils, as found above in (**31**). The individual part fluxes of the rotor tooth opposite the primary coil, that is, the fluxes for the angles u and v in Fig. 13 forming part of tooth R can be determined by a

similar simple calculation. After all part fluxes are known, the densities follow, of course, directly.

Let us assume for the present a field distribution for the resultant rotor field as shown in Fig. 14, and if we assume further that the flux in tooth N of Fig. 13 is represented by the area

$$\varphi_N = n\, n_1\, p_1\, p$$

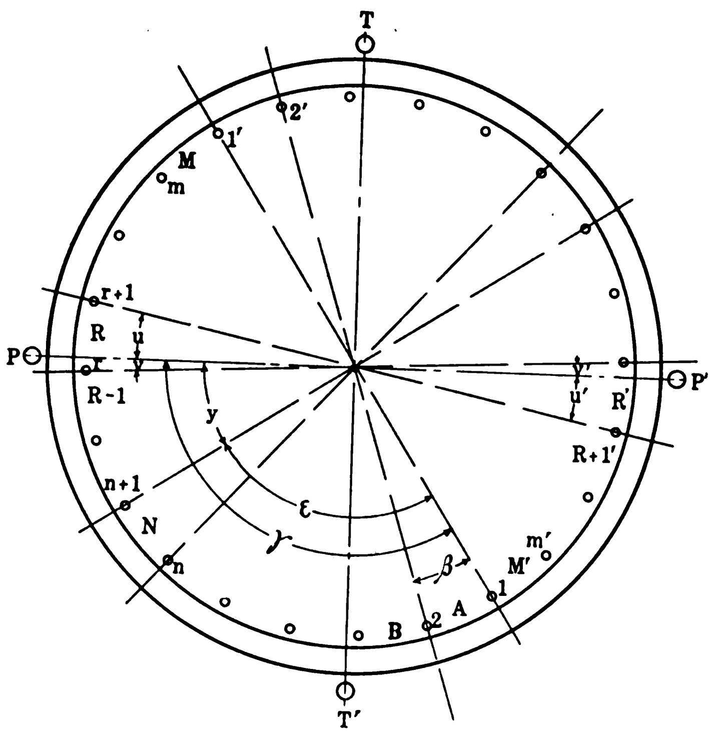

Fig. 13

and that of the opposite tooth N' by

$$\varphi_{N'} = n'\, n_1'\, p_1'\, p'$$

Let further

$$\begin{aligned} \text{area } n\, p\, P &= Y \\ \text{“ } P\, n'\, p' &= Y' \\ \text{“ } n_1\, p_1\, P &= X \\ \text{“ } P\, n_1'\, p_1' &= X' \end{aligned}$$

The resultant flux in coil n is then according to Fig. 14

$$\varphi_n = Y - Y' \qquad (32)$$

and that in coil $n + 1$ is

$$\varphi_{n+1} = X - X' \qquad (33)$$

It follows further from the figure that

$$Y = X + \varphi_N$$
$$Y' = X' - \varphi_{N'} \qquad (34)$$

therefore, we can write (32) by introducing these values

$$\varphi_n = X + \varphi_N - X' + \varphi_{N'} \qquad (35)$$

or since obviously opposite teeth carry the same amount of flux and, therefore,

$\varphi_N = \varphi_{N'}$, we get

$$2\,\varphi_N = \varphi_n - (X - X') = \varphi_n - \varphi_{n+1}$$
$$\varphi_N = \tfrac{1}{2}\,[\varphi_n - \varphi_{n+1}] = \qquad (36)$$
$$\frac{\varphi}{2} \quad [\cos(\gamma - (n-1)\,\beta) - \cos(\gamma - n\,\beta)]$$

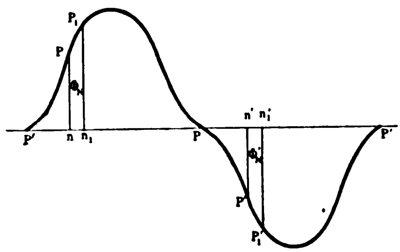

FIG. 14

It appears that the teeth fluxes found from (36) are independent of α and, therefore, constant. They are also uniformly distributed over the entire tooth width in all teeth except in the teeth R and R', which are influenced by the currents in P and P'.

It is evident from Fig. 13 that

$$\varphi_R = \varphi_v + \varphi_u \qquad (37)$$

also that

$$-\varphi_i = \varphi_v + \varphi_{R-1} + \,\ldots\ldots\ldots\, \varphi_B$$
$$+ \varphi_A + \,\ldots\ldots\ldots\, \varphi_{R+1'} + \varphi_{u'} \qquad (38)$$

Since obviously $\varphi_{u'} = -\varphi_u$ and since all values in (38) except φ_i, φ_v and $\varphi_{u'}$ have been found to be constant, we can write

$$-\varphi_i = \varphi_v - \varphi_u + K_2 \qquad (39)$$

where $K_2 = \Sigma\,\varphi$ from φ_{R-1} to $\varphi_{R+1'}$.

By adding (**37**) and (**39**) we find

$$\varphi_v = \tfrac{1}{2}(\varphi_R - \varphi_i - K_2) \qquad (\mathbf{40})$$

and

$$\varphi_u = \tfrac{1}{2}(\varphi_R + \varphi_i + K_2) \qquad (\mathbf{41})$$

We know from (**36**) that

$$\varphi_R = \frac{\varphi}{2}\left[\cos(\gamma - (r-1)\,\beta) - \cos(\gamma - r\,\beta)\right]$$

and

$$\varphi_i = \varphi \cos \alpha$$

therefore, we can now determine φ_v and φ_u in terms of α for the time

$$\alpha = -u \text{ to } \alpha = v.$$

Since $\cos \alpha$ enters the values for φ_v and φ_u, we find that while the sum of the two is constant, each of the two values varies with the time.

For the time $\alpha = v$ to $\alpha = v + \beta$ the tooth $R - 1$ is under the influence of $P\,P'$ and its part fluxes can be similarly determined, etc.

With the tooth fluxes known, the densities follow directly to be

$$B_N = \frac{\varphi_N}{\beta} K$$

etc.

also,

$$B_v = \frac{\varphi_v}{v} K \qquad (\mathbf{42})$$

$$B_u = \frac{\varphi_u}{u} K$$

The step lines of Fig. 15 represent the resultant field distribution for a motor, as per Fig. 13, with $m = 6$, that is, with six secondary slots per pole for various values of α and under the assumption that γ = a multiple of β, which means that one of the secondary coils coincides with P for $\alpha = 0$ and the maximum value of the flux φ_i.

It is plainly evident again from Fig. 15 that the resultant field travels with the secondary. The sine curves shown in the figure, as well as equation (**36**), reveal the fact that the sine curve cuts the center of each step. This fact applies to any polyphase rotor, even Case No. 2, although it was not so evident there. In other words, we see that the magnetizing currents in the secondary create as much as possible a resultant rotating field of sinusoidal

space distribution, even with the unfavorable rectangular distribution of the primary field assumed in our present case. The resultant field will approach a sinusoidal distribution the closer the larger the number of secondary teeth and the more the secondary resistance approaches the zero value.

Every slot, primary or secondary, produces a step, unless the current in the slot happens to be zero. It will further be seen that the flux of each secondary tooth is, of course, uniformly distributed over the tooth, except in the tooth opposite to the primary slot; in this case, the ampere conductors in the primary

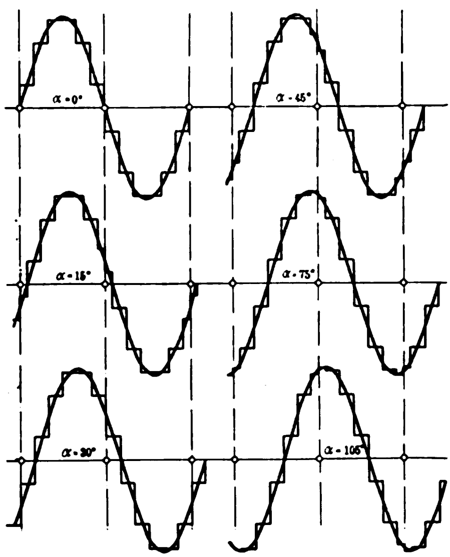

FIG. 15

slot form an additional step, without, however, changing the total flux of the particular secondary tooth.

The currents could again be determined as in the previous cases, by setting the sum of all magnetomotive forces acting upon each tooth or its parts proportional to the known densities. This would, with many coils, lead to an impractical amount of calculations. A much simpler method follows from the simple consideration that the difference between the densities adjacent to each slot is naturally caused by the ampere conductors in the slot.

If we make again the previous assumptions of uniform reluc-

tances, etc., this fact points to the natural conclusion that the difference in the densities at each side of a slot is proportional to the ampere conductors in the slot. This in turn gives, for our present problem, *a fifth fundamental condition to be met* (which now takes the place of the third condition utilized previously), namely, that with densities for all tooth portions being definitely established by other conditions, *the ampere conductors of each slot must at any time be proportional to the difference in magnetic densities at the two sides of the slot.*

Since the densities of all tooth portions are known, this condition offers a very simple way for finding the current in the various coils by simply finding the difference of the tooth densities at each side of the conductors. Definite and fully determined current values can thus be found in all cases except when a rotor and a stator coil coincide, in which case, it is not directly known how the total magnetomotive force distributes between the two coils; this latter exception was discussed in detail under Case No. 1.

In order to obtain the correct mathematical relations, reference may be made to equation (**5**), from which the ampere turns necessary to obtain a certain density may be found. While equation (**5**) was written for the single primary coil, the same law applies to any coil with a current i_n turns N_n producing a density B. We have, therefore,

$$i_n = \frac{B}{N_n} \, \frac{1}{K_l} \text{ or,}$$

$$B = i_n \, n_n \, K_l$$

Now it is evident that if a single coil produces a density B, we will have a density of say $+ B$ at one side of the slot and $- B$ at the other side, giving a difference B_d between the densities on both sides of the slot of

$$B_d = B - (- B) = 2 \, B = 2 \, i_n \, n_n \, K_l \text{ or,}$$

$$i_n = B_d \, \frac{1}{2 \, n_n \, K_l} \tag{43}$$

With the exception previously stated, we find, therefore,

$$i_1 = (B_{M'} - B_A) \, \frac{1}{2 \, n_1 \, K_l}$$

$$i_2 = (B_A - B_B) \frac{1}{2\, n_2\, K_l}$$

etc.

$$i_n = (B_{N-1} - B_N) \frac{1}{2\, n_n\, K_l} \tag{44}$$

$$i_r = (B_{R-1} - B_v) \frac{1}{2\, n_n\, K_l} \tag{45}$$

$$i_p = (B_v - B_u) \frac{1}{2\, n_p\, K_l} \tag{46}$$

$$i_{r+1} = (B_u - B_{R+1}) \frac{1}{2\, n_{r+1}\, K_l} \tag{47}$$

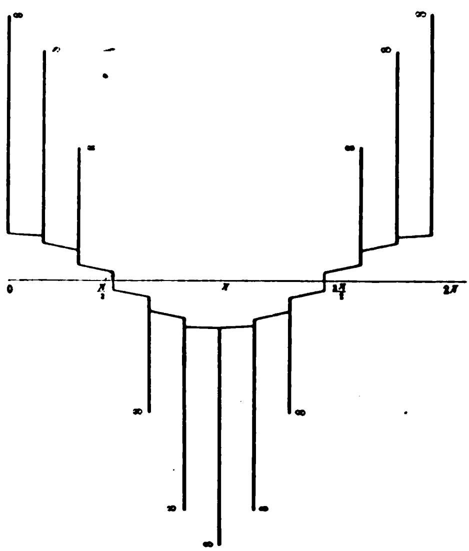

FIG. 16A

Since all values of these equations, except B_v, and B_u are constant, it follows that all current except i_r, i_p and i_{r+1} are constant for the time $\alpha = -u$ to $\alpha = v$.

For the next following time $\alpha = v$ to $\alpha = v + \beta$ all currents except i_{r-1}, i_p and i_r are constant, etc. In other words, it follows that any of the secondary currents are constant, except when either of the adjacent teeth of the coil under consideration passes P or P'.

Fig. 16 shows the primary and secondary current curves for the same case as assumed in Fig. 15. In accordance with our

fourth fundamental condition, the ∞ negative values are again indicated by the heavy vertical lines in connection with the secondary currents. Each of the $-\infty$ values reflects into the primary, so that the primary current has a number of those heavy vertical lines shown.

A close study of the secondary currents reveals that each of the currents is uniform for the largest part of the time. The uniform current value is a sine function of the space angle between the particular coil and coil 1.

When the tooth adjacent to the coil under consideration begins to coincide with P or P', the current decreases along part

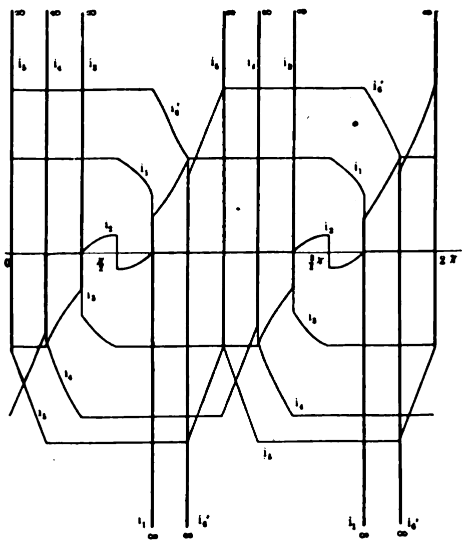

FIG. 16B

of a sine curve until the coil coincides with P or P', when an infinite negative value is reached for an instant. Subsequently, the current increases again along part of a sine curve, while the other adjacent tooth passes P, until the previous constant value is reached again and maintained until the coil approaches the next primary slot.

These general characteristics apply to all cases considered so far. The constant current value over a certain period does, however, not exist in Figs. 3, 7 and 9, of case 1 and 2, because there is at all times at least one tooth adjacent to each secondary slot coinciding with a primary slot. Therefore, we have in

these cases only those parts of the secondary current curves which are infinite or those which follow parts of sine curves. In practise, the infinite values will, of course, again be changed to definite high current peaks as pointed out in Case No. 1.

The determination of the tertiary voltages by means of the previous methods with a number of equations would again be very laborious in the present case. We have found, however, that the density over each secondary tooth is uniform and constant unless it coincides with a primary slot. Since in our case, a secondary tooth passing the tertiary slots T or T' never coincides at the same time with the primary slot P or P', as

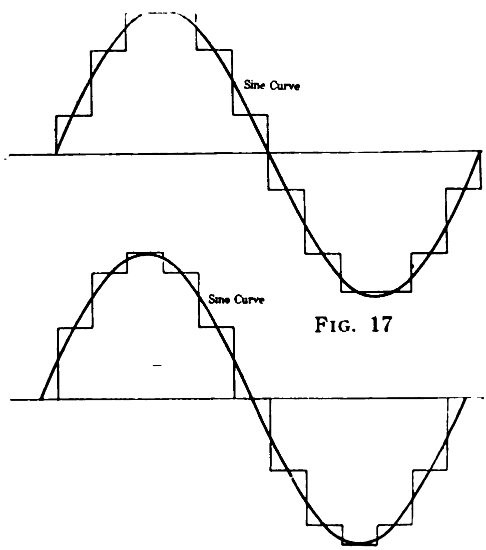

FIG. 17

FIG. 18

long as $m \geqq 2$, each tooth flux and density remains constant, while passing and cutting the tertiary conductors.

The determination of the tertiary voltage is, therefore, very simple in connection with the present case, if we apply the theory of cutting magnetic lines in place of figuring with the interlinking fluxes. The tertiary voltage is then simply to be set proportional to the density of the teeth passing the coil sides.

If we determine, therefore, from previous formulas the resultant field form, disregarding the extra step caused temporarily by the primary in each secondary tooth while it passes a primary slot, we have at the same time the tertiary voltage

wave. Figs. 17 and 18 show the resultant field and tertiary voltage wave, thus determined for six secondary slots per pole. Fig. 17 applies for $\gamma = 0$, that is, under the assumption that a secondary slot happens to coincide with the primary slot at the time $\alpha = 0$, while Fig. 18 applies for $\gamma = \frac{\beta}{2}$, that is, when the middle of a secondary tooth happens to coincide with the primary slot at the time $\alpha = 0$.

With an asynchronous machine, the small slip will gradually change the values of γ and, therefore, the conditions from that of Fig. 17 to that of Fig. 18. This means that the tertiary voltage again changes its shape as in the previous case while the rotor slips against the stator.

With the wave shape of the tertiary voltages at hand, it is comparatively simple to find the effective tertiary voltage values by simply calculating the r.m.s. value of the step curve.

Referring back to Fig. 13, it is evident that all secondary conductors are alike and that nothing is changed if the conductors are numbered, starting with 1 at the conductor just approaching slot P, that is, numbering the conductor marked "r" with No. 1. This simply means that γ is a fraction of β. Let us now set

$$\gamma = a\ \beta = a\ \frac{\pi}{m}$$

where according to the above, a is a true fraction and $\beta = \frac{\pi}{m}$ follows from the fact that we have m teeth per pole, *i.e.*, for the arc π. Introducing this in equation (**42**) for B_N, and using equation (**36**) for φ_N, we obtain

$$B_N = \frac{\varphi_N\ m}{\pi} K = \frac{\varphi\ m\ K}{2\ \pi}$$

$$\left[\cos\left(a - (n+1)\frac{\pi}{m}\right) - \cos\left((a - n)\frac{\pi}{m}\right)\right] \quad (\mathbf{48})$$

From this it can be shown that all teeth from A to M inclusive, have positive densities for values of $a = 0$ to $a = \frac{1}{2}$. The effective value of the total positive wave can, therefore, be found, by considering the teeth A to M, inclusive, while $a = 0$ to $a = \frac{1}{2}$. The effective value of the total positive wave can, therefore, be found by

considering the teeth a to m, inclusive, while $a = 0$ to $a = \frac{1}{2}$. Similarly, the teeth B to A' have to be considered while $a = \frac{1}{2}$ to $a = 1$.

The effective density value and, therefore, the effective tertiary voltage is proportional to the square root of the mean height of the area, showing the square values of all positive densities. The area of each step of the curve is

$B_N^2 \frac{\pi}{m}$, therefore, the total area is

$$\Sigma\, B_N^2 \frac{\pi}{m} \Big|_A^M \quad \text{and}$$

$$e_T \text{ effective} \cong \sqrt{\frac{\Sigma\, B_N^2 \frac{\pi}{m}}{\pi}} \Bigg|_A^M = \sqrt{\frac{\Sigma\, B_N^2}{m}} \Bigg|_A^M \qquad (49)$$

By introducing B_N from (**48**) into (**49**) the tertiary voltage follows directly.

It will again be found, as in Case No. 2 that as long as $m \geqq 2$, the effective tertiary voltage is constant, and independent of γ, although the wave shape is continuously changing with γ. The curve of Fig. 19 shows the tertiary voltages as obtained from (**48**) and (**49**) for various numbers m of secondary slots per pole in terms of the primary voltage, assuming equal number of turns in both windings.

The difference between the two effective voltages is caused principally by the difference in field forms, interlinking with the primary winding and that inducing voltages in the tertiary winding. Such differences are usually taken into account under the names of zig-zag and differential leakage. Therefore, we may call the difference between the values of curve 19 and one, the differential plus zig-zag leakage coefficient; its value is indicated by the right-hand scale in Fig. 19. It will be seen that even with the small number of stator slots assumed so far, a relatively small number of rotor slots is sufficient to reduce this leakage coefficient to a very low value. The leakage coefficient thus found and shown in Fig. 19 seems to conform to the following simple equation

$$\sigma = \frac{0.4}{m^2}$$

With our present assumptions, this represents all the so-called zig-zag leakage; the leakage value usually going under the name of differential leakage is zero in our case.

Case No. 4

Single Primary Coil, Infinite Number of Secondary Phases

The erratic shape of the primary current curve with infinite theoretical values has made a quantitative calculation of the effective primary current value difficult for practical use in all previous cases. The theoretical case of an infinite number of secondary coils and a single primary coil, in which higher harmonic primary currents cannot exist, lends itself better for this particular purpose and may, therefore, be considered next.

The relations derived for the previous case apply, of course,

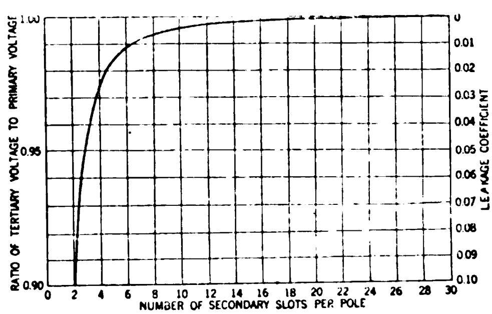

Fig. 19

here if the proper substitutions are made by simply introducing an infinite number of infinitely small secondary teeth into the equations.

Take $$\beta = d\,\epsilon$$

and $$n\,\beta = n\,d\,\epsilon = \epsilon$$

It follows from (**31**) by introducing these values

$$\begin{aligned} \varphi_{n-1} &= \varphi \cos(\gamma - \epsilon + 2\,d\,\epsilon) \\ \varphi_n &= \varphi \cos(\gamma - \epsilon + d\,\epsilon) \\ \varphi_{n+1} &= \varphi \cos(\gamma - \epsilon) \end{aligned} \qquad \textbf{(50)}$$

Similarly, it follows from (**36**)

$$B_N = \frac{\varphi_N}{d\,\epsilon} K$$

$$= \frac{\cos(\gamma - \epsilon + d\,\epsilon) - \cos(\gamma - \epsilon)}{d\,\epsilon} \frac{\varphi}{2} K$$

and
$$B_{N-1} = \frac{\varphi_{N-1}}{d\,\epsilon} K$$

$$= \frac{\cos\,(\gamma - \epsilon + 2\,d\,\epsilon) - \cos\,(\gamma - \epsilon + d\,\epsilon)}{d\,\epsilon} \frac{\varphi}{2} K$$

or

$$\left.\begin{aligned} B_N &= \frac{\varphi}{2} K \frac{d\,[\cos\,(\gamma - \epsilon)]}{d\,\epsilon} \\ &= \frac{\varphi}{2} K \sin\,(\gamma - \epsilon) \\ B_{N-1} &= \frac{\varphi}{2} K \frac{d\,[\cos\,(\gamma - \epsilon + d\,\epsilon)]}{d\,\epsilon} \\ &= \frac{\varphi}{2} K \sin\,(\gamma - \epsilon + d\,\epsilon) \end{aligned}\right\} \quad (52)$$

It follows directly from (**52**) that the local distribution of the actual resultant rotor flux follows a sine law around the rotor, so that a constant rotor field with sinusoidal distribution rotates with the rotor. This simply means that the steps of the field form found in the previous case are infinitely small, therefore, giving a smooth sine curve.

The density of the field is zero for $\gamma - \epsilon = 0$, that is, at the conductor 1. With these facts known, we can, therefore, plot the resultant rotor field φ_s as shown in Fig. 20 for various values of α under the assumption that $\gamma = 0$.

In determining now the nature of the secondary currents, we proceed again as in the previous case, except that we consider the ampere conductors over an infinitely small angle $d\,\epsilon$ of the secondary in place of the current per secondary coil.

By substitution of the values from (**52**) and (**44**), we find the secondary ampere turns $i_n\,n_n$ over any space angle $d\,\epsilon$ for any time, except the moment when the particular angle $d\,\epsilon$ passes the coil P, to be as follows:

Considering the ampere turns of an angle $d\,\epsilon$ extending an angle of $\frac{d\,\epsilon}{2}$ to either side of the coil point n we have,

$$i_n\,n_n = \frac{1}{2\,K_l} (B_{N-1} - B_N)$$

$$= \frac{\varphi K}{4 K_l} [\sin (\gamma - \epsilon + d \epsilon) - \sin (\gamma - \epsilon)]$$

$$= \frac{\varphi K}{4 K_l} d [\sin (\gamma - \epsilon)] \tag{53}$$

$$= - \frac{\varphi K d \epsilon}{4 K_l} \cos (\gamma - \epsilon)$$

It follows from (**53**) that the local ampere-turns distribution around the rotor circumference follows a cosine law, except at the point of the primary coil.

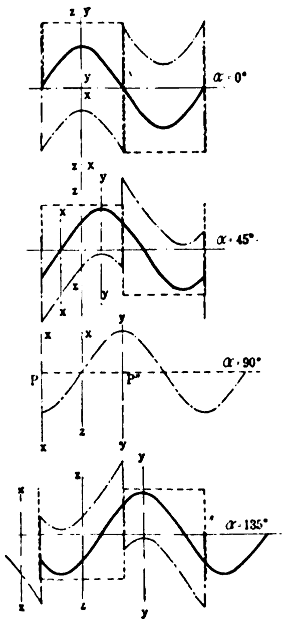

FIG. 20

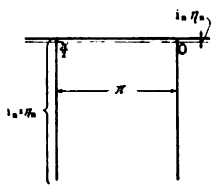

FIG. 21

This is again in line with the previous case, except that the secondary ampere conductors for each infinitely small angle are infinitely small during the periods of constant positive current.

Since the area of the positive wave of the secondary currents has in consequence of this an infinitely small value, we cannot any longer conclude that the negative current values must be infinite, when the secondary coil point passes the primary. On the contrary, we can determine certain definite negative current values.

We know from the previous case that the current in each secondary coil reverses when the particular coil passes the primary coil. The size of the reversed current can be determined from the following consideration. We found that if the flux within a rotor coil decreases after the coil has passed the primary coil, it must increase again to its original value, when it coincides again with the primary coil. In other words, if the flux φ_n decreases according to a function $f(\alpha)$ for a certain time, it must increase again according to some function $f_1(\alpha)$ before the time π has gone by. Now we know that if the current in the coil during the time of decreasing flux is a function $F(\alpha)$ and another function $F_1(\alpha)$ during the remaining time, the voltage which must be induced in the coil follow functions $r\,F(\alpha)$ and $r\,F_1(\alpha)$.

Therefore, we must have

$$\frac{d\,f(\alpha)}{d\,\alpha} = r\,F(\alpha)$$

and

$$\frac{d\,f_1(\alpha)}{d\,\alpha} = r\,F_1(\alpha) \tag{54}$$

and since we know that the sum of all $d\,f(\alpha)$ must be equal to the sum of all $d\,f_1(\alpha)$ we can write

$$r\int F(\alpha)\,d\,\alpha = r\int F_1(\alpha)\,d\,\alpha \tag{55}$$

where the first integral is to be taken for the limits between which the current is positive and the second integral for the limits between which the current is negative. In our case, we know the current to be i_n, that is, a constant and of uniform direction during the time $(\pi - d\,\alpha)$ and of opposite direction during $d\,\alpha$, we have therefore,

$$\int_0^{\pi-d\alpha} F(\alpha)\,d\,\alpha = \int_0^{\pi-d\,\alpha} i_n\,d\,\alpha = i_n\,(\pi - d\,\alpha)$$

and if the current i_{nx} in opposite direction is assumed to be constant during the infinitely short time $d\,\alpha$, we have

$$\int_{\pi-d\,\alpha}^{\pi} F_1(\alpha)\,d\,\alpha = \int_{\pi-d\,\alpha}^{\pi} i_{nx}\,d\,\alpha, \text{ therefore,}$$

$$i_n\,(\pi - d\,\alpha) = -\,i_{nx}\,d\,\alpha$$

or,

$$i_{nx} = - i_n \frac{\pi - d\,\alpha}{d\,\alpha} \qquad (56)$$

$$i_{nx} = \frac{\pi - d\,\alpha}{d\,\alpha} \; \frac{\varphi}{4} \; \frac{K}{K_l} \; d\,\epsilon \cos(\gamma - \epsilon) \qquad (57)$$

Since both $d\,\alpha$ and $d\,\epsilon$ are indefinitely small, it follows that i_{nx} must not any longer be infinite as in the previous cases.

It will be seen from (**57**) that the values for the negative secondary ampere conductors $i_{nx}\, n_n$ are proportional to cos $(\gamma - \epsilon)$. The time curve of the current conductors in any of the secondary coils appears, therefore, as shown in Fig. 21, if we imagine the value $i_n\, n_n$ infinitely small.

The determination of the primary current values follows again from the condition that the known resultant field must be proportional to the sum of the magnetizing effect of the primary ampere turns and the just determined secondary ampere turns.

With uniformly distributed secondary conductors, it is again immaterial which coil point is numbered 1, and we may, thereore, make $\gamma = 0$, which merely means that coil point 1 happens to coincide with P when $\alpha = 0$. It further means that any coil n passes P at the time $\alpha = - \epsilon$. This follows directly from Fig. 13.

A coil point with $\epsilon = - \frac{\pi}{2}$ therefore, passes P at the time $\frac{\pi}{2}$. It follows also from (**53**) and (**57**) that both the positive and negative currents in this conductor are zero. Reference to Fig. 20 for $\alpha = 90$ deg. $= \frac{\pi}{2}$ further reveals that at that time the resultant flux in the axis $Z\,Z$ of the primary coil is zero, and that the sine-shape flux curve has its maximum at the primary coil point $P\,P'$. This, in turn, means that there is no change in flux density at these points (the differential coefficient of a cosine curve being zero at its maximum value), and, therefore, no resultant ampere conductors acting. It follows directly that under this condition and with the secondary coil points at P and P' carrying zero current, the primary current for $\alpha = \frac{\pi}{2}$

must also be zero. We know further that all other secondary coil points carry at this moment positive currents as per equation (**53**), and evidently the resultant field at the time $\frac{\pi}{2} = \alpha$ must be induced by these currents alone. Since the field is constant, we know, therefore, that the positive secondary currents alone are just sufficient to induce the necessary resultant field. From this, we can at once derive our *sixth fundamental condition* applying only to the present case, namely, that ***the sum of the primary ampere conductors and the negative ampere conductors of the secondary coil points coinciding with the primary coil point must be zero at all times.***

This leads to the following calculation, resulting in a formula for the primary magnetizing current.

With $\gamma = 0$, each secondary coil point n passes the primary coil at the time $\alpha = -\epsilon$ and it follows therefore from (**57**) and the condition just stated, that the primary ampere turns at the time α must be

$$\dot{i}_p\, n_p = \dot{i}_{nx}\, n_n = \frac{\pi - d\,\alpha}{d\,\alpha}\ \frac{\varphi}{4}\ \frac{K}{K_l}\, d\,\epsilon \cos(-\,\epsilon) \tag{58}$$

where $-\,\epsilon = \alpha$

In this equation, we may neglect the infinitely small $d\,\alpha$ as compared to π and let $\pi - d\,\alpha = \pi$. We may further let $d\,\epsilon = d\,\alpha$, both being infinitely small and obtain

$$\dot{i}_p\, n_p = \frac{\pi}{4}\,\varphi\,\frac{K}{K_l} \cos\alpha \tag{59}$$

We find the crest value of the current

$$I_p = \frac{\pi}{4}\ \frac{\varphi}{n_p}\ \frac{K}{K_l} \tag{60}$$

It follows from (**59**) that the primary current follows a cosine law, as is to be expected with an impressed sinusoidal voltage and a rotating field with sinusoidal distribution.

We know from (**5a**) the value with open secondary, and, therefore, find the ratio of the open to the closed secondary magnetizing current in the primary to be

$$\frac{\frac{\pi}{4}}{\frac{1}{\pi}} = \frac{\pi^2}{4} = 2.45 \text{ for the present case.}$$

Knowing the flux set up by the primary at each instant, namely,

$$\varphi_p = \left(\frac{\pi}{2}\right)^2 \varphi \cos \alpha$$

and the resultant flux φ_s, the flux set up by the secondary currents, being the difference of the two, can now be easily plotted for the various values of α as in Fig. 20. It will be seen that the flux furnished by the secondary has a rather peculiar space distribution, being the difference between a sinusoidal and rectangular distribution field form. The traveling of the resultant field and the secondary magnetomotive forces is again the same as in previous cases.

The tertiary voltage is in this case evidently of the same value and curve shape as the impressed voltage, the zig-zag and belt leakage being obviously zero.

Case No. 5

Primary Sinusoidal Distribution, Infinite Number of Secondary Phases With Negligible Resistance and Leakage

One of the reasons why the previous cases with a concentrated primary winding were taken up so much in detail, is because it can be definitely proved in these cases, that the resultant rotating field approaches a sinusoidal distribution very closely in spite of the very unfavorable rectangular field form set up by the primary winding. With this fact established, it is obvious that with a distributed primary winding giving in itself a sinusoidal field distribution, a similar resultant field will exist. If we assume further an infinite number of secondary coils, together with the previous assumptions of an impressed primary sinusoidal voltage, a true sinusoidal resultant field will undoubtedly obtain and can simply be used as the basis for all calculations. Similar considerations, together with results obtained in Case No. 4, justify, under these conditions, the assumption of a sinusoidal primary current wave, shifted 90 deg. against the impressed voltage wave. Such an ideal case may now be considered to good advantage because the knowledge of this and the previous opposite extremes is helpful in the understanding of the more practical cases.

With the self-evident assumptions just made, the resultant ampere conductors, that is, the sum of the primary and secondary at each point of the circumference, can again be found from our fifth fundamental condition, that the ampere conductors of each

point must be the difference of the magnetic densities at either side of the point under consideration.

Having thus a means for determining the resultant ampere conductors, and knowing laws for the time curve of the primary current, as well as for the distribution of the primary and secondary conductors, we can easily write down a number of equations expressing these laws, and which are necessary for determining the numerical values of the currents.

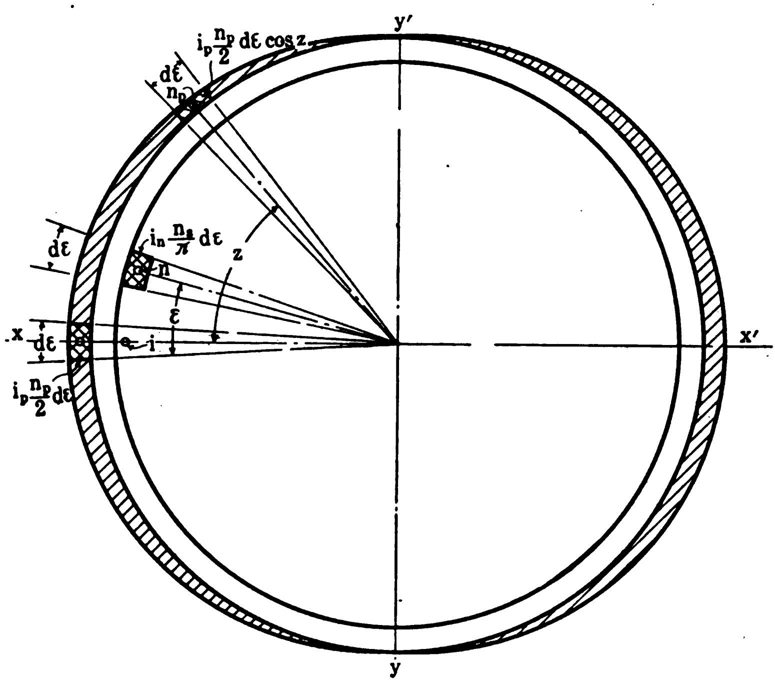

FIG. 22

It is well known that the flux needed to induce the proper counter e. m. f. with a sinusoidal winding distribution, is as a matter of course, larger than with a concentrated coil, which can be taken care of by the usual voltage winding coefficient. The latter is in the present case $c = \frac{\pi}{4}$ so that

$$\varphi = \frac{4}{\pi}\,\varphi_c, \tag{63}$$

if φ_c is the flux as found from formula (**2**) for a concentrated primary winding.

If the total number of primary turns is again n_p and if they are first assumed to be uniformly distributed over the pole arc π we would have $i_p \frac{n_p\, d\,\epsilon}{\pi}$ ampere turns for an infinitely small angle $d\,\epsilon$. With sinusoidal distribution, as shown in Fig. 22, we find a maximum value of ampere turns, by multiplying this average with $\frac{\pi}{2}$ which gives

$$i_p \frac{n_p}{\pi} d\,\epsilon \frac{\pi}{2} = i_p \frac{n_p}{2} d\,\epsilon$$

at the center $x\,x'$ of the primary phase belt. A value for the ampere turns at a point n_p an angle z away from this center, is consequently

$$i_p \frac{n_p}{2} d\,\epsilon \cos z$$

The instantaneous primary current values following a cosine law are under the assumption of the crest value I_p.

$$i_p = I_p \cos \alpha$$

and the ampere turns of a space angle $d\,\epsilon$ are

$$i_p\, n_z = I_p \cos \alpha \frac{n_p}{2} d\,\epsilon \cos z \tag{64}$$

We know further from previous considerations, equation (**53**), that the resultant ampere turns at a rotor point n, an angle ϵ ahead of coil number 1, must be

$$i_{rn}\, n_{rn} = - \frac{\varphi}{4} \frac{K}{K_l} d\,\epsilon \cos (\gamma - \epsilon) \tag{65}$$

It was also pointed out that the ampere turns furnished by the secondary must be at any point of the circumference and at any time the difference

$$i_p\, n_z - i_{rn}\, n_{rn} = i_n\, n_n \tag{66}$$

For the sake of simplicity, we may again number the secondary coil points so that point 1 coincides with the center of the primary phase belt at the time $\alpha = 0$ which simply means that $\gamma = 0$ in the formula for $i_{rn}\, n_{rn}$. This also means that the rotor coil n coincides

with a stator coil point, which is an angle ϵ from the center at the time $\alpha = 0$ and angle $\epsilon + \alpha = Z$ at the time α.

Thus we can write by setting $n_n = \frac{n_s\, d\,\epsilon}{\pi}$ and by introducing into (**66**) the values from (**64**) and (**65**)

$$I_p \cos \alpha \frac{n_p}{2}\, d\,\epsilon \cos (\epsilon + \alpha) + \frac{\varphi}{4}\ \frac{K}{K_l}\, d\,\epsilon \cos (-\epsilon)$$

$$= i_n \frac{n_s\, d\,\epsilon}{\pi} \qquad \textbf{(66 A)}$$

Since both the maximum primary current I_p and the secondary current are unknown in the single equation derived in (**66 A**) we again make use of our fourth fundamental condition that the resultant secondary current area over the time π must be zero, in order to obtain another equation.

We know from the above that the secondary coil n coincides with the center of the primary phase belt at the time $\alpha = -\epsilon$ and $\alpha = -\epsilon + \pi$ and that the integration of the secondary currents between these times must be zero.

Therefore, we have, if we let $d\,\alpha = d\,\epsilon$

$$\int_{\alpha=-\epsilon}^{\alpha=-\epsilon+\pi} \Big[I_p \cos \alpha \frac{n_p}{2}\, d\,\alpha \cos (\epsilon + \alpha)$$

$$+ \frac{\varphi}{4}\ \frac{K}{K_l}\, d\,\alpha \cos (-\epsilon) \Big] = 0$$

from which we find

$$I_p = -\frac{\varphi}{n_p}\ \frac{K}{K_l} \qquad \textbf{(67)}$$

For open-circuited secondary, we can find from a simple calculation

$$I_p = -\frac{\varphi}{2\, n_p}\ \frac{K}{K_l} \qquad \textbf{(68)}$$

With I_p known, we can find $i_n\, n_n$ from (**66A**) for any point n of the secondary,

$$i_n\, n_n = i_n \frac{n_s}{\pi}\, d\,\epsilon = \frac{K}{K_l}\, d\,\epsilon \frac{\varphi}{2} \left(\frac{\cos(-\epsilon)}{2} \right.$$

$$\left. - \cos \alpha \cos (\alpha + \epsilon) \right)$$

or

$$i_n \, n_s = \frac{K}{K_l} \; \frac{\pi}{4} \; \varphi \cos \left(2 \, \alpha + \epsilon \right) \qquad \textbf{(69)}$$

It will be seen from **(67)** and **(68)** that the primary magnetizing current with closed and synchronously rotating secondary is, therefore, just twice the magnetizing current with open secondary. This is in line with the assumption usually made in commercial designing.

Fig. **23** shows the secondary currents for a number of secondary points corresponding to various values of ϵ, as well as the primary current.

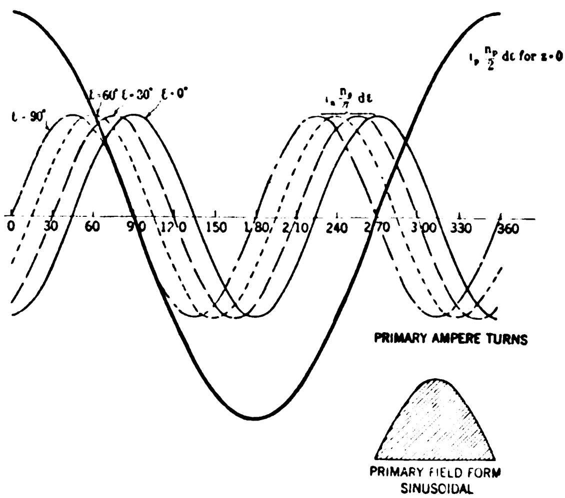

FIG. 23

It will be seen that all the secondary currents are in this case double frequency sinusoidal currents, with the same maximum values of

$$I_n = \frac{\pi}{4} \; \frac{\varphi}{n_s} \; \frac{K}{K_l} \qquad \textbf{(69A)}$$

Fig. 23A shows the fields, or rather the magnetomotive forces as furnished by the primary and the secondary, as well as the resultant field, all of which have a sinusoidal local distribution in this particular case. This figure shows better, than those previously given, the fundamental characteristics of the fields and how they travel. The primary magnetomotive force with the axis $z z$ is, of course, not rotating, but stationary and al-

ternating; that is, varying in size and polarity. The resultant field with the axis *y y* of practically constant size travels, relative to the stator, at uniform speed and synchronously with the secondary member to the right. The magnetomotive forces furnished by the secondary currents with the axis *x x* are also practically constant in size and travel with equal speed, relative to the stator, to the left. Relative to the synchronously rotating secondary, the resultant field is, therefore, fixed, while the secondary magnetomotive force rotates with double synchronous speed in a backward direction. Such double speed field or rather

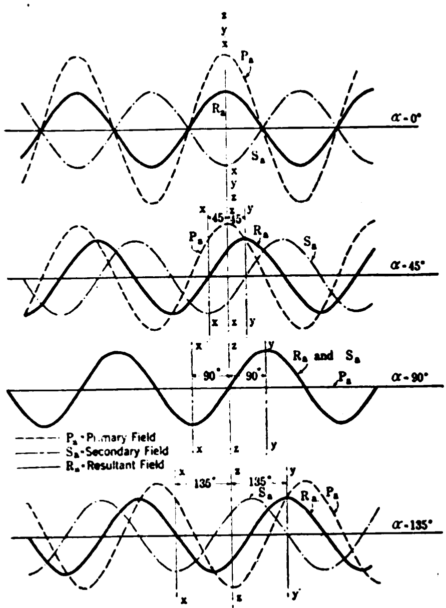

FIG. 23A

magnetomotive force in the secondary is, of course, to be expected in so far as the secondary currents are known to be double-frequency polyphase currents. While the primary field may be considered as the sum of the field set up by the secondary and of the resultant field from a purely mathematical point of view, as has been done at times, it should be kept in mind that actually the primary field is primarily induced from the line; its existence, in turn, causes double-frequency currents in a synchronously rotating rotor which, if they are imagined to exist without primary currents, would induce a field rotating opposite in direction

to the mechanical direction of rotation. As previously mentioned, the speed of this imaginary field is synchronous relative to the primary and double synchronous relative to the rotor. Stating the facts physically correct, we may say that the stationary and alternating primary magnetomotive forces of line frequency, together with the double-line-frequency secondary magnetomotive forces, combine to induce a resultant field which

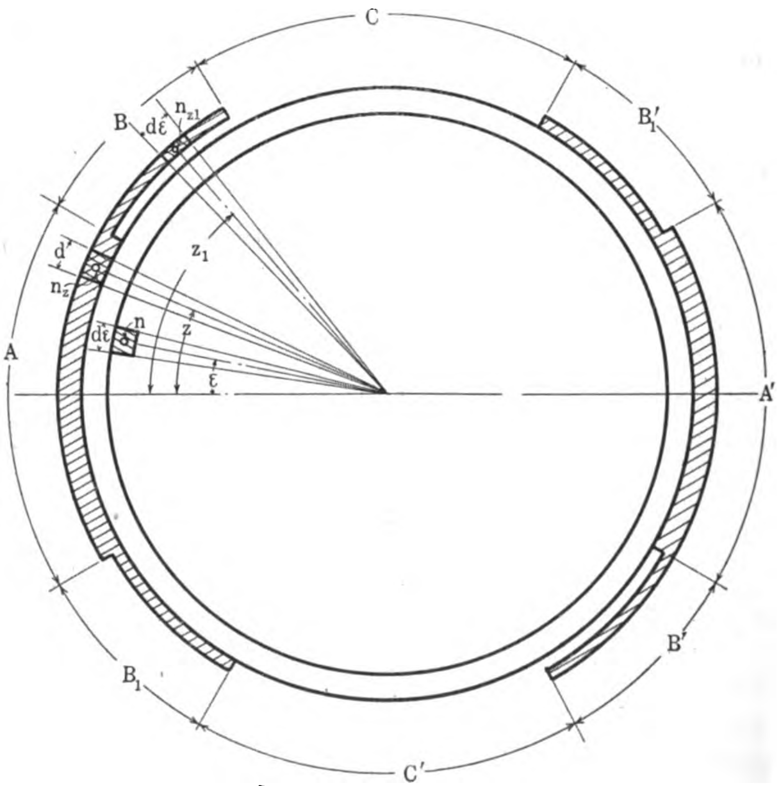

Fig. 24

rotates in the same direction as the mechanical rotation of the secondary and with the same speed relative to the primary.

Case No. 6

Primary Field Form Consisting of Straight Line Functions, Infinite Number of Secondary Phases

In practise, it is difficult to obtain sinusoidal distribution of the primary winding, and, therefore, winding distributions as shown in Fig. 24 are usually resorted to; such distribution can

be easily obtained by either concentric windings or chorded diamond coils.

While it is possible with such windings to induce sinusoidal counter e.m.fs. with resultant fields having other than sinusoidal distributions, it may at present be assumed that a sinusoidal distribution of the resultant field exists as in all previous cases of an infinite number of secondary phases. Such a field will always induce sinusoidal counter e.m.fs., thereby satisfying our first fundamental condition.

In view of the strong tendency for the establishment of a resultant sinusoidal field previously demonstrated, this assumption is quite justified, provided, of course, that our other fundamental conditions can be met satisfactorily under this assumption.* The following calculations will show that this is the case.

For similar reasons, a sinusoidal time curve for the primary current may at present also be assumed.

The general method for determining the desired quantities is in the present case the same as in the previous case. The only difference is that the distribution of the primary conductors does not any longer follow a single law all around the circumference, making it necessary to consider the different portions A, B, and C, in Fig. 24 individually in the calculation, this leads naturally to more complicated equations.

If the total primary turns again n_p, we find that an angle $d\,\epsilon$ within the angle A has $\frac{n_p\, d\,\epsilon}{(A + B)}$ turns, while an equal angle $d\,\epsilon$ within the angles B and B_1 usually has $\frac{n_p\, d\,\epsilon}{2\,(A + B)}$ turns.

A secondary coil point n, an angle ϵ shifted against point 1 must again have the resultant ampere turns—see equation (53)

$$i_{rn}\, n_{rn} = - \frac{\varphi}{4} \frac{K}{K_l}\, d\,\epsilon \cos(-\,\epsilon) \text{ if } \gamma = 0 \qquad (70)$$

*NOTE: It should be remembered that our considerations so far still assume uniform magnetic reluctance, negligible resistances and leakage reactances, etc. In practical machines, both single-phase and polyphase operated, it is quite possible and in practise often actually experienced, that the resultant field form has higher harmonics, caused by magnetic densities in the iron, bad distribution of resistance between bars and rings of squirrel-cage windings, etc. These are important problems in themselves and will be made the subject of a separate study, apart from the present paper.

While passing the angles C and C', which occurs during the times

$$\alpha = \frac{A}{2} + B - \epsilon \text{ to } \alpha = \frac{A}{2} + B + C - \epsilon$$

and

$$\alpha = \frac{3\,A}{2} + 3\,B + C - \epsilon \text{ to } \alpha = \frac{3\,A}{2} + 3\,B + 2\,C - \epsilon$$

no other ampere turns act upon this point and these ampere turns must, therefore, be furnished by the rotor, so that

$$\dot{i}_n\, n_{nc} = \dot{i}_{rn}\, n_{rn}$$

While the same secondary point passes any of the angles A or B, we must find the secondary ampere turns as the difference of the primary and the resultant ampere turns.

Point n passes the angles B during the times

$$\alpha = \frac{A}{2} - \epsilon \text{ to } \alpha = \frac{A}{2} + B - \epsilon$$

$$\alpha = \frac{A}{2} + B + C - \epsilon \text{ to } \alpha = \frac{A}{2} + 2\,B + C - \epsilon$$

etc.

During this time, we must have

$$\dot{i}_n\, n_{nB} = -\, I_p \cos \alpha \frac{n_p\, d\,\epsilon}{2\,(A + B)}$$

$$- \frac{\varphi}{4}\, \frac{K}{K_l}\, d\,\epsilon \cos(-\,\epsilon) \qquad \textbf{(71)}$$

Point n passes the angles A during the times

$$\alpha = -\,\frac{A}{2} - \epsilon \text{ to } \alpha = \frac{A}{2} - \epsilon$$

and

$$\alpha = \frac{A}{2} + 2\,B + C - \epsilon \text{ to } \alpha = \frac{3\,A}{2} + 2\,B + C - \epsilon$$

During this time, we must have

$$\dot{i}_n\, n_{nA} = -\, I_p \cos \alpha \frac{n_p\, d\,\epsilon}{A + B}$$

$$- \frac{\varphi}{4}\, \frac{K}{K_l}\, d\,\epsilon \cos(-\,\epsilon) \qquad \textbf{(72)}$$

We know again that the integral of $i_n\, n_n$ between

$$\alpha = \frac{\pi}{2} - \epsilon \text{ to } \alpha = \frac{3\,\pi}{2} - \epsilon \text{ must be zero,}$$

that is,

$$\int_{\frac{\pi}{2}-\epsilon+\frac{C}{2}+B}^{\frac{\pi}{2}-\epsilon+\frac{C}{2}+B+A} i_n\, n_{nA} + \int_{\frac{\pi}{2}-\epsilon+\frac{C}{2}}^{\frac{\pi}{2}-\epsilon+\frac{C}{2}+B} i_n\, n_{nB}$$

$$+ \int_{\frac{\pi}{2}-\epsilon+\frac{C}{2}+B+A}^{\frac{\pi}{2}-\epsilon+\frac{C}{2}+2B+A} i_n\, n_{nB} + \int_{\frac{\pi}{2}-\epsilon}^{\frac{\pi}{2}-\epsilon+\frac{C}{2}} i_n\, n_{nC}$$

$$+ \int_{\frac{\pi}{2}-\epsilon+2\,B+A+\frac{C}{2}}^{\frac{3\,\pi}{2}-\epsilon} i_n\, n_{nC} = 0 \qquad (73)$$

This equation applies only as long as $\epsilon < \frac{\pi}{2}$ but similar equations follows in other cases. By substitution, we find from this

$$I_p = -\frac{\pi\,(A+B)}{4\left(\sin\frac{A}{2} + \cos\frac{C}{2}\right)}\;\frac{\varphi}{n_p}\;\frac{K}{K_l} \qquad (74)$$

The flux is in this case again

$$\varphi = \frac{1}{c}\,\varphi_c \qquad (75)$$

if φ_c the flux required with a concentrated primary coil. The coefficient c is in this case

$$c = \frac{2\sin\frac{A+B}{2}}{A+B}\,\cos\frac{B}{2} \qquad (75\text{ A})$$

With diamond shaped chorded coils

$$\frac{2\sin\frac{A+B}{2}}{A+B}$$

corresponds to the usual distribution factor and

$$\cos \frac{B}{2} = \sin \frac{\pi - B}{2}$$

corresponds to the usual chord factor.

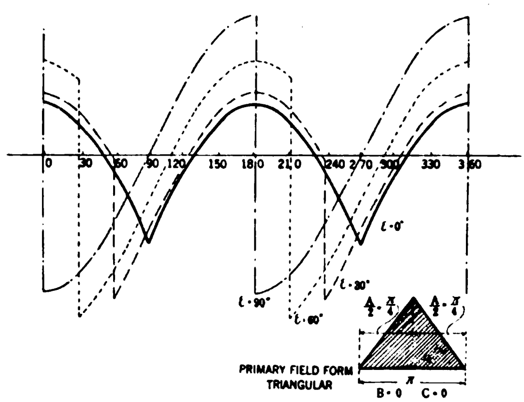

FIG. 25

It will be seen in (74) that ϵ has cancelled out which means that a primary current following a cosine law, together with a sinusoidal resultant field fulfills in each secondary coil located

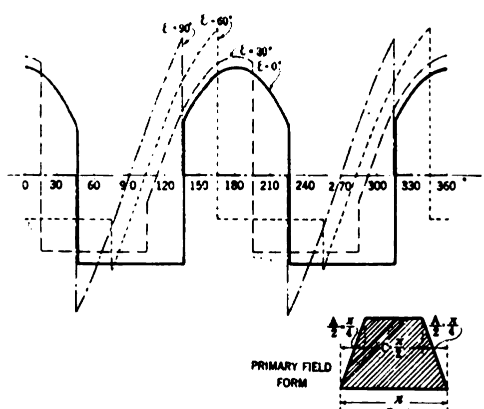

FIG. 26

at any angle ϵ away from coil 1 the condition that the average current in the coil is zero. This being the case, we have shown that the assumptions of a sinusoidal space distribution of the resultant field and a sinusoidal time curve for the primary cur-

rent made in the beginning of this case were correct under our present conditions.

Figs. 25 to 29, inclusive, show the curves for the secondary currents for a number of different field forms. Fig. 25 covers the case of a triangular field form for which the currents corresponding to $\epsilon = 0$ are rather small, while those corresponding to $\epsilon = 90$ deg. are rather large. Fig. 28 gives the case of a machine in which the winding is uniformly distributed over 120 deg. as would be the case in a full-pitch three-phase machine run single-phase. As compared with the previous case, the currents corresponding to $\epsilon = 0$ have increased, and those corresponding to $\epsilon = 90$ deg. have decreased. Fig. 27 gives the case of a machine in which the primary winding is uniformly distributed over 90

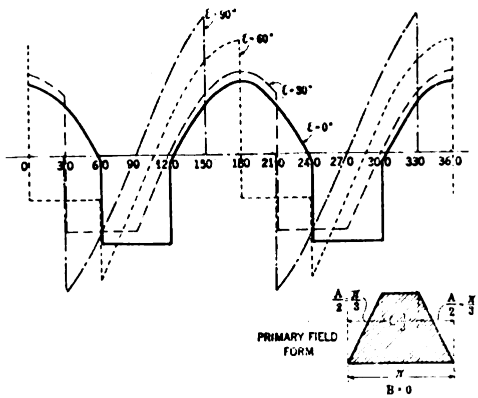

FIG. 27

deg., as would be the case in a full-pitch two-phase machine run single phase. As compared with the previous case, the currents corresponding to $\epsilon = 0$ have again increased, and those corresponding to $\epsilon = 90$ deg. have decreased. Fig. 28 shows the case of a primary winding which is practically concentrated. It will be realized that even with a primary winding wound into one coil, the field form will not be truly rectangular, but somewhat as shown in Fig. 28. Accordingly, the secondary currents will not assume infinite values as theoretically found in connection with Case No. 4, but it will be somewhat similar to those shown in Fig. 28. Fig. 29 corresponds to a winding in which A is 90 deg., B 35 deg., and C 20 deg. As will be seen from the figure, the primary field form approaches in this case very closely a sinusoidal curve. While the primary current from (**74**) is, in

this case, only one per cent different from that obtained with a sinusoidal distribution, it will be seen that the secondary currents are still very much different from a sinusoidal double-frequency curve. This shows that even the slightest departure from the sinusoidal curve necessary for practical reasons leads to very irregular secondary current curves, although the departure from a sinusoidal curve is the smaller the closer the primary distribution approaches such a curve.

Fig. 27A shows the magnetomotive forces furnished by the primary and the secondary, as well as the resultant field for the

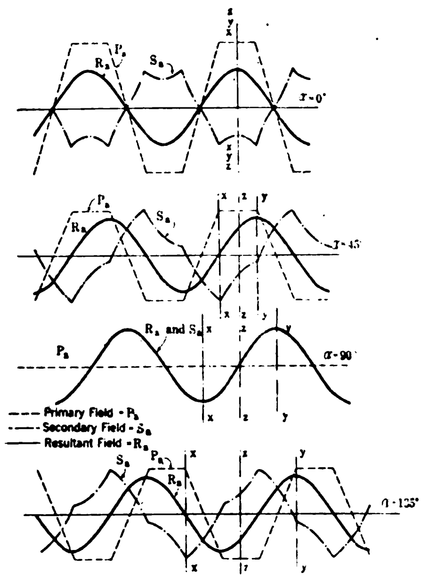

FIG. 27A

case covered in Fig. 27. It can be noted again that the secondary magnetomotive force travels in a direction opposite to the resultant field; its distribution assumes, however, in contradistinction to Fig. 23A, rather irregular shapes, being always the difference between the primary trapezoid and the resultant sine curve.

CASE NO. 7

Primary Distribution According to a Function $f(z)$, Infinite Number of Secondary Phases

It is evident that the methods used in the previous cases can be applied to any distribution of primary ampere turns. If the

primary field form is made up from portions of straight lines, each of them being a function $f\ (z)$, the method of Case No. 6 can be applied, no matter what the number of different straight lines is. Naturally, the equations will become rather

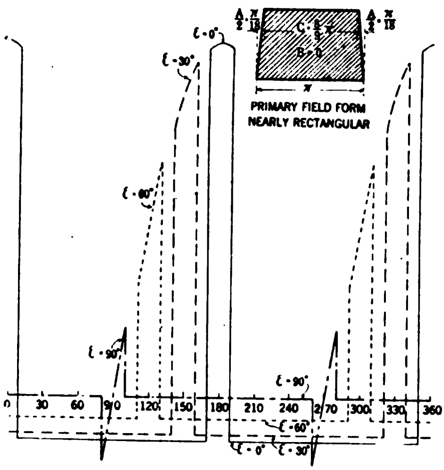

FIG. 28

long and complicated, if the field form is composed of many different lines. In certain cases, it may, therefore, be simpler to resolve the primary field form into a single equation of a funda-

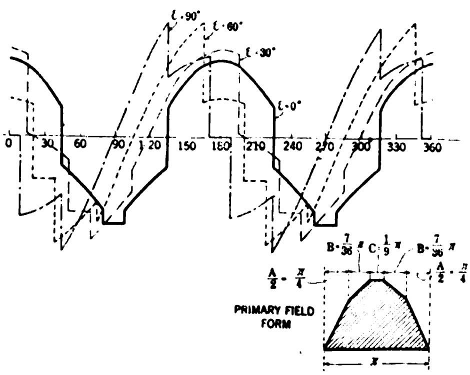

FIG. 29

mental sine wave and its higher harmonics, and then proceed as in Case No. 5. In this case, a single function $f\ (z)$ applies for the whole cycle. In such cases, the function may, however, be such as to lead to complications in connection with the inte-

gration necessary for finding I_p. Thus the one on the other method may be found more convenient, depending upon the case.

Case No. 8

Primary Winding Distributed in Closed Slots, Infinite Number of Secondary Phases

In actual practise, field forms and distributions of primary ampere turns can be approximately obtained as shown under Case No. 6 by skewing either the stator or the rotor one primary slot pitch. The practise of skewing slots meets, however, with certain practical difficulties, especially with large machines and, therefore, it is of interest to determine the influence of the straight standard slot. The use of slots for locating the primary ampere turns, which brings about a concentration of the ampere turns in a number of points instead of uniform distribution as assumed in Case No. 6, leads to field forms as shown in a full line Fig. 30A instead of that shown by a dotted line in the same figure and corresponding to the case of Fig. 27. As pointed out under Case No. 7, it is possible to treat such a case along the same lines as described under Case No. 6, which requires, however, a considerable amount of calculation, especially with a large number of slots.

For these reasons, the description of a graphical method for determining the secondary currents may be of interest. This method, which is based on the facts previously determined, introduces a slight theoretical error, which, however, is of no practical importance. On the other hand, the graphical method gives a much clearer picture of what happens in the machine than can be obtained from the previous formulae.

We have previously found that the resultant flux rotating with the rotor of an infinite number of phases is nearly constant and has a sinusoidal local distribution around the surface. From this we further concluded that with uniform air-gap reluctance, we must have at all times at any synchronously rotating rotor point a resultant constant number of ampere turns, the size of which follows a cosine low around the rotor. Line A B in Fig. 30C may represent this constant resultant ampere-turn value for a certain point. Now we know that such resultant value is at any time the sum of the rotor ampere turns at this point and of the stator ampere turns which happen to be located opposite to this rotor point during the time element under consideration.

Let us assume, for instance, a case as assumed in Fig. 27 and a rotor point corresponding to $\epsilon = 0$; this means the rotor point passing the center of the primary phase belt at $\alpha = 0$, that is, at the time when the primary current reaches its maximum value.

Fig. 30B shows the dotted areas $a\ a'\ b'\ b$ representing the

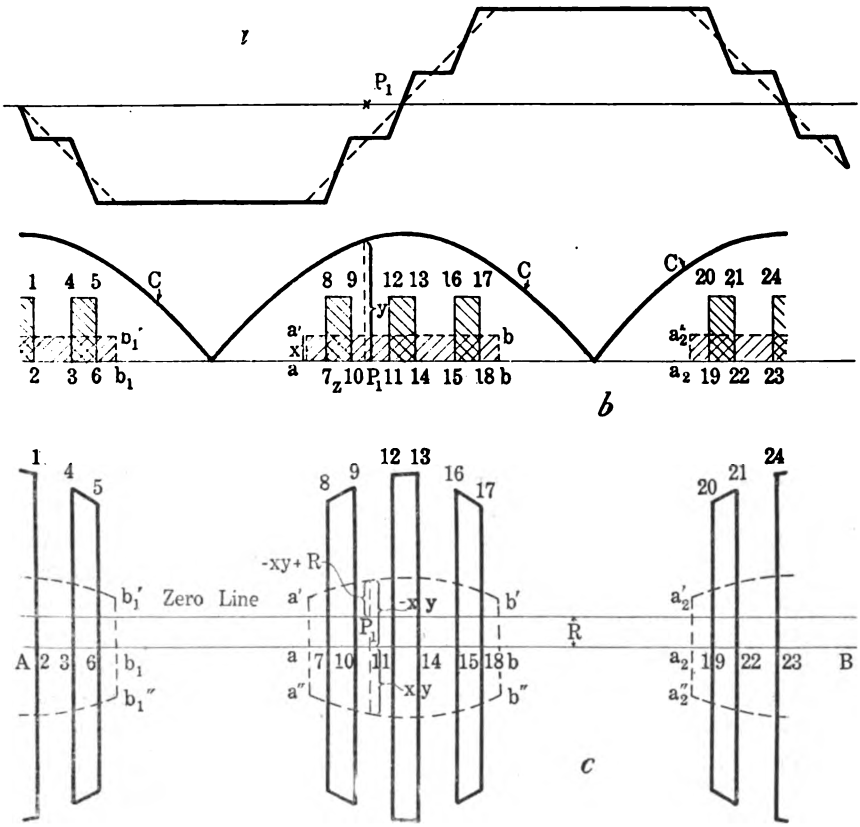

Fig. 30

primary winding belts. While our rotor point travels from b_1 to a and from b to a_2, it is not acted upon by any primary ampere turns, which means that the secondary ampere turns are identical with the resultant. Therefore, the portions b_1 to a and b to a_2 of the line $A\ B$ of Fig. 30c represent portions of the secondary ampere-turn time curve.

The sine curve C represents the time curves of the primary

current as found from formula (74) for this case plotted so against the circumference, that y represents the time value of the primary current, when our point has reached a point P_1 on the stator circumference. If we multiply, therefore, y with the turns located at this point, we get the number of stator ampere turns acting upon our point, when it has reached point P_1 on the stator.

These ampere turns $x\ y$ act in the same direction as the resultant ampere turns R represented by line $A\ B$ in Fig. 30c. If we add $x\ y$ to $A\ B$ as shown, we obtain the sum of the primary and resultant ampere turns, and it is also evident that the rotor ampere turns must be the difference between $-\ x\ y$ and R as shown. By proceeding similarly for all other points, we obtain the heavy dotted line $b_1'\ b_1\ a\ a'\ b'\ b\ a_2\ a_2'$, representing the time curve of the secondary current, which corresponds exactly to the curve for $\epsilon = 0$ in Fig. 27. The distance between $A\ B$ and the light dotted curves $a\ a''\ b''\ b$ etc., represent the primary ampere turns.

Let us assume now, for instance, that the same number of primary turns are concentrated in three equally spaced slots as represented by the areas 7, 8, 9, 10, 11, 12, 13, 14 and 15, 16, 17, 18 in Fig. 30B. We know then from a number of previous considerations that the primary current still follows a sine law, if the number of secondary phases is infinite. The maximum value of the primary current is slightly changed by the change made, but it can be shown that the error in assuming it to be the same as before is less than one or two per cent in the majority of cases. Therefore, we can proceed just as described before and obtain very close values for the secondary ampere turns as represented by the full line curve 1, 2, 3, 4, 5, 6, 7, etc. in Fig. 30c. It is at once evident that the effective or heating value of this curve is considerably larger than that of the dotted curve.

Case No. 9

Primary Winding Distributed in Open Slots, Infinite Number of Secondary Phases

In all previous cases, the resultant ampere turns of a given point were assumed to be proportional to the difference in density of the adjacent surface portions. This assumption is practically correct in most cases of closed and partially closed slots. With wide open slots, it will, however, be necessary to take the variations of the air gap reluctance into account. This can be

done very easily with the method shown under Case No. 8. It is merely necessary to replace the straight line *A B* of Fig. 30c by a curve *A C B*, as shown in Fig. 31, such curve representing the varying reluctance of the air gap caused by the slot openings and with it, the varying resultant ampere turns required to bring about the practically constant flux condition necessary for equilibrium. The secondary ampere turns can then be found just the same as in Fig. 30, except that the distances *x y* are entered, starting from the curve *A C B* in Fig. 31 instead of from the straight line *A B* in Fig. 30c.

In this manner, we obtain the heavy line curve 1, 2, 3, 4, 5, etc., giving the secondary current and ampere turns. It will be seen that higher harmonics are introduced all over the secondary current cycle, at the same time, the maximum peaks have been reduced as compared with the previous case.

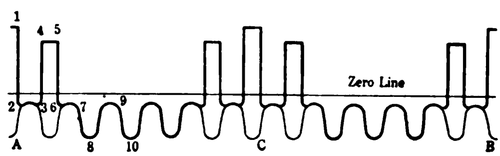

Fig. 31

Case No. 10

Primary Winding Distributed in Slots, Polyphase Secondary Winding Distributed in Slots

The case with both primary and secondary winding distributed over a limited number of non-skewed slots found most commonly in practice requires an altogether impractical amount of calculation for its correct treatment. It will be shown, however, that for a well balanced design, very close results can be obtained by the aid of the facts established with the previous cases.

We have found in connection with cases Nos. 1, 2 and 3 (see in particular Figs. 13 and 16) that each secondary slot reflects into the concentrated primary winding, while passing the same, a very high current peak. Such peak is infinite if the secondary coil is concentrated in a mathematical point and under the assumption of no leakage reactance. In practise, neither of the latter assumptions apply. The fact that the secondary slots, even if practically closed, distribute the effect of the secondary ampere turns over a certain distance on account of the flux

dispersion, changes the infinite values of infinitely short duration to definite values still rather large and of relatively short duration. The difference between the theoretical primary current curve and the actual caused by the fact that the effect of the secondary coil is not concentrated in a point is the same as the difference between the secondary currents of Fig. 16 and those of Fig. 28. The leakage reactance present in every machine serves further to reduce the height of the higher harmonic current peaks, especially since they are of rather high frequency. Since the secondary flux dispersion around the slots, as well as the leakage reactance, vary over wide ranges in different designs, it is difficult to give a general rule regarding the exact height of the higher harmonic current peaks actually obtained in case of Fig. 16. It is evident, however, that in this case, peaks of such magnitude

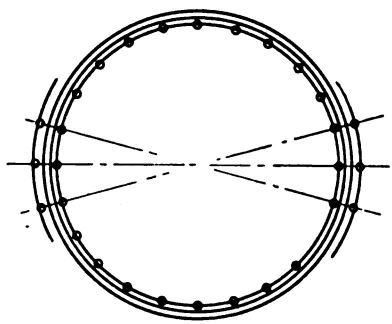

FIG. 32

may be obtained to cause an appreciable difference between the actual primary current curve and a sinusoidal curve. Since the nature of this actual curve cannot easily be determined, the method of Cases No. 8 and 9 for the determination of the secondary currents, or any of the other methods cannot be readily employed.

If the primary winding is distributed over a number of slots of the same pitch as the secondary slot, as shown in Fig. 32, conditions are practically the same as before. Each of the secondary currents has, in the case assumed, three reversed current peaks, as shown in Fig. 30, instead of one, as shown in Fig. 28, each of the three peaks being about one-third of the single peak. Since, however, three secondary coils coincide simultaneously with the three primary coils, three secondary current peaks of one-third size are reflected at the same time

into the primary, giving again rather bad peaks in the primary current wave. Experience with noise, dead points, etc. has long ago taught designers to avoid equal tooth pitch in both members, and relative tooth pitches, as shown in Fig. 33 are commonly used. In this case, only one secondary slot coincides at the time with a primary coil so that the secondary reflects for each high peak in Fig. 16, several smaller peaks into the primary. Both the higher frequency and the smaller amplitude of these peaks, together with the effect of the leakage in most practical machines, iron the higher harmonics out to such an extent that the departure of the actual primary current wave from the sinusoidal can be neglected in most well designed machines. Therefore, it is permissible to assume primary currents as calculated from (**57**) for the investigation of most practical cases,

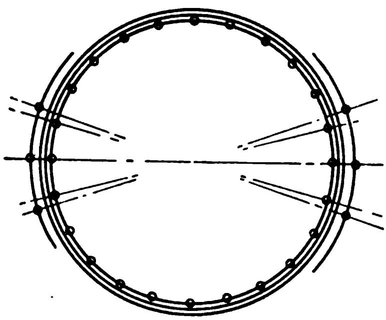

FIG. 33

although small errors may be introduced even in well designed machines and appreciable errors in some extreme cases.

With a primary current wave established, the method of Case No. 8 may be applied to a limited number of secondary coils with certain modifications.

We must now consider the fact that no matter what the distribution of the primary ampere turns is, the fluxes will always distribute fairly uniform over a secondary tooth. Assume, for instance, again the same primary winding and field as in case of Fig. 27 and Fig. 30. If we have then a secondary slot n located at a point x as shown in Fig. 34A, it is evident that the flux between the points $n - 1$ and n will distribute uniformly over the secondary tooth N, as indicated by a dotted line 1, 2. Similarly, the flux between n and $n + 1$ will distribute uniformly over the tooth $N + 1$, as indicated by the dotted line 3, 4. The result is, there-

fore, the same as if a number of primary turns proportional to the vertical line 2, 3 were concentrated in the point x. By determining the length of 2,3 in this manner for a number of locations of the point x, we obtain a curve a, b, c, d, shown in Fig. 34B which represents the equivalent primary distribution of turns. The corresponding current values are again represented by the sine curve which, as previously pointed out, is only an approximation. By multiplying the values of the two curves, we obtain,

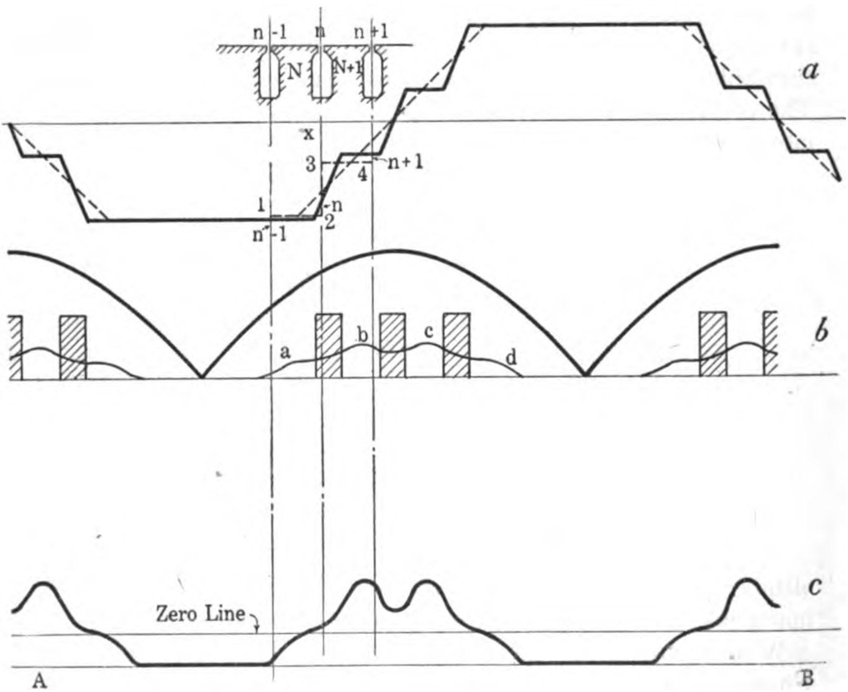

FIG. 34

as before, in Fig. 34c the time curve for the secondary ampere turns for $\epsilon = 0$. By comparison with Fig. 30c, it will be seen that the high peaks, and with them the losses, have been materially reduced by going from an infinite or a very large number of secondary slots to a number of slots only slightly different from the number of primary slots. Similar improvements will be obtained in case of open slots, if the secondary slot pitch approaches the primary slot pitch.

Case No. 11

Squirrel-Cage Rotors

In all previous cases, a polyphase rotor with coils was assumed, and accordingly, the fact that the flux within the secondary coils is approximately constant was used as a basis for the calculation. In practice, short-circuit or damping windings of the squirrel cage type are more commonly employed. With such windings, each tooth is surrounded by a short-circuited turn, which means that the tendency is to keep the flux within each tooth constant. It has been shown, however, under Case No. 3 that the tooth fluxes must also be constant with a coil winding and it appears, therefore, that the fundamental conditions are the same in both cases and that the results obtained for coils are equally applicable to the bars of squirrel-cage windings.

Case No. 12

Synchronous Machines

The previous considerations apply principally to induction machines, but it is evident that the methods given can be readily used in connection with synchronous machines. The only thing changed is that certain or all current points in the secondary carry a constant direct current. In considering these points, the constant d-c. ampere turns furnished from an outside source must be taken into consideration in the various equations for the ampere turns.

Case No. 13

Primary Sinusoidal Distribution, Infinite Number of Secondary Phases, Resistance and Leakage Reactance Taken Into Account

So far, the resistances were assumed to be negligible in all cases; this assumption holds approximately true at no-load with large machines, as for instance, phase converters for locomotives. Single-phase induction motors are, however, principally built for very small sizes with which the influence of the resistances may be appreciable even at no-load.

The influence of the secondary resistance in case of sinusoidal primary field distribution with an infinite number of secondary slots may now be investigated.

For zero resistances, we found the instantaneous current values of the primary and secondary, respectively, to be

$$i_p = I_p \cos \alpha$$

$$i_n = I_n \cos (2\,\alpha + \epsilon) \text{ (see } \mathbf{(69)}\text{)}$$

Resistance in the secondary may change both the phase relations and the crest values I_p and I_n of the currents. If we designate by θ the change in phase angle of the primary current and by ρ the corresponding change in the secondary current, we have, therefore, the new relations

$$i_p = I_p \cos(\alpha + \theta) \tag{76}$$

and

$$i_n = I_n \cos(2\alpha + \epsilon + \rho) \tag{77}$$

wherein at present I_p, I_n, θ and ρ are unknown.

In order to send the currents i_n through the secondary coils with a resistance r_n, we must induce voltages $e_n = i_n r_n$ in the coils. Knowing this, as well as the law of change for i_n from (**77**), we can easily find the law for the flux changes necessary in each coil to induce the voltages e_n. In other words, we find the conditions which the flux has to fulfill to obtain equilibrium in the secondary circuits. By determining further, as in all previous cases, the conditions which the flux has to fulfill for giving equilibrium in the primary circuit, we can definitely determine the actual fluxes satisfying both primary and secondary. The following calculation carried out along these lines give all desirable information about the fluxes.

Assume again as in the previous cases that each secondary coil n an angle ϵ ahead of coil 1 passes the center of the primary belt at the time $\alpha = -\epsilon$.

The voltage to be induced in a coil n is according to the above considerations

$$e_n = i_n r_n = I_n r_n \cos(2\alpha + \epsilon + \rho) \tag{78}$$

Therefore, the rate of change of the flux within the coil must be

$$\frac{d\varphi_{ni}}{d\alpha} = e_n = I_n r_n \cos(2\alpha + \epsilon + \rho) \tag{79}$$

From which we find

$$\varphi_{ni} = \frac{1}{2} I_n r_n \sin(2\alpha + \epsilon + \rho) + C \tag{80}$$

wherein C is the integration constant.

The latter is found by considering the required flux relations with regard to the primary. Let us assume at present that the flux within each primary coil follows a sine law and that the flux interlinking with the center of the primary coil belt has its maximum value φ at

the time $\alpha = 0$, as in all previous cases. Then the instantaneous flux value interlinking with this center is

$$\varphi_i = \varphi \cos \alpha$$

Since each secondary coil n coincides with the primary belt center for $\alpha = -\epsilon$, the flux within the secondary coil n at this time must be

$$\varphi_{ni} = \varphi_i = \varphi \cos \alpha = \varphi \cos (-\epsilon) \qquad \textbf{(81)}$$

or if we combine **80** and **81** for $\alpha = 0$

$$\varphi \cos (-\epsilon) = \frac{1}{2} I_n r_n \sin (-\epsilon + \rho) + C$$

or

$$C = \varphi \cos (-\epsilon) - \frac{1}{2} I_n r_n \sin (-\epsilon + \rho) \qquad \textbf{(82)}$$

and introducing this into (**80**), we get

$$\varphi_{ni} = \varphi \cos (-\epsilon) + \frac{1}{2} I_n r_n [\sin (2\alpha + \epsilon + \rho) - \sin (-\epsilon + \rho)] \qquad \textbf{(83)}$$

According to previous considerations, we know that the flux φ_N of an infinitely small secondary tooth N is one-half the difference between the fluxes of the two adjacent coils n and $n + 1$, an angle $d\epsilon$ apart; therefore, we have

$$\varphi_N = \frac{\varphi_{(n+1)i} - \varphi_{ni}}{2}$$

$$= \frac{1}{2}\Big[\varphi \cos (-(\epsilon + d\epsilon)) - \varphi \cos (-\epsilon) + \frac{1}{2} I_n r_n \Big(\sin (2\alpha + \epsilon + d\epsilon + \rho) - \sin (2\alpha + \epsilon + \rho) - \sin (-(\epsilon + d\epsilon) + \rho) + \sin (-\epsilon + \rho)\Big)\Big] \qquad \textbf{(84)}$$

From this we find the density

$$B_N = \frac{\varphi_N}{d\epsilon} K = \frac{K}{2}\Big[-\varphi \sin (-\epsilon) + \frac{1}{2} I_n r_n \Big(\cos (2\alpha + \epsilon + \rho) - \cos (-\epsilon + \rho)\Big)\Big] \qquad \textbf{(85)}$$

In order to check our previous assumptions regarding the flux interlinking with the center of the primary phase

belt, we determine now the voltage induced in the primary. Equation (**85**) represents the flux distribution around the secondary in terms of ϵ. The distribution around the primary in terms of Z follows directly from the fact that we always have

$$z = \epsilon + \alpha \text{ or } \epsilon = z - \alpha$$

Introducing this into (**85**) we get,

$$B_Z = \frac{\varphi z}{d_Z} = \frac{K}{2}\Big[-\varphi \sin(\alpha - z)$$

$$+ \frac{1}{2} I_n r_n \Big(\cos(\alpha + z + \epsilon + \rho) - \cos(\alpha - z + \rho)\Big)\Big] \qquad \textbf{(86)}$$

The total flux interlinking with a coil z extending from z to $z + \pi$ is

$$I_n = \frac{\varphi}{r_n} \sin\rho = \frac{K}{K_l}\frac{\varphi}{4}\frac{\pi}{n_s} \frac{1}{\sqrt{1 + \left(\frac{K}{K_l}\frac{r_n}{n_s}\frac{\pi}{4}\right)}} \qquad \textbf{(95a)}$$

This permits the determination of I_n.

Let us now consider the center of the primary phase belt, *i.e.*, point x and x' with $z = 0$, and assume further $\alpha = 0$, at which time the secondary coil 1 with $\epsilon = 0$ coincides with x and x'.

Introducing these values into (**93**), we get

$$I_n \frac{n_s}{\pi} \cos\rho + I_p \frac{n_p}{2} \cos\theta =$$

$$-\frac{K}{4 K_l}\Big[\varphi + \frac{1}{2} I_n r_n \;(\sin(-\rho) - \sin\rho)\,)\Big]$$

or

$$\cos\theta = -\frac{2}{I_p n_p}\left(\frac{K}{K_l}\frac{\varphi}{4} + I_n \frac{n_s}{\pi}\cos\rho\right)$$

$$\cos\theta = -\frac{\varphi}{2 I_p n_p}\frac{K}{K_l}(1 + \cos^2\rho) \qquad \textbf{(96)}$$

Let us further consider the center of the primary phase belt for $\alpha = \frac{\pi}{2}$ at which time a secondary coil with $\epsilon = -\frac{\pi}{2}$ coincides with x and x'.

Introducing these values into (**93**), we get

$$I_n \frac{n_s}{\pi} \cos\left(\frac{\pi}{2} + \rho\right) + I_p \frac{n_p}{2} \cos\left(\frac{\pi}{2} + \theta\right) = 0$$

or

$$I_p = - I_n \frac{n_s}{n_p} \frac{2}{\pi} \frac{\cos\left(\frac{\pi}{2} + \rho\right)}{\cos\left(\frac{\pi}{2} + \theta\right)}$$

or by introducing I_n as found in (**95**) we get

$$I_p = - \frac{K}{K_l} \frac{\varphi}{2} \frac{1}{n_p} \frac{\sin \rho \cos \rho}{\sin \theta} \qquad \textbf{(97)}$$

or

$$I_p = - \frac{K}{K_l} \frac{\varphi}{2} \frac{1}{n_p} \frac{\frac{1}{2} \sin 2\rho}{\sin \theta} \qquad \textbf{(97-A)}$$

By introducing this into (**96**) we get

$$\frac{\cos \theta}{\sin \theta} = \tan \theta = \frac{\sin \rho \cos \rho}{1 + \cos^2 \rho} = \frac{1}{2} \frac{\sin 2\rho}{1 + \cos^2 \rho} \qquad \textbf{(98)}$$

We are now in a position to calculate all currents and their phase relations correctly for any rotor resistance. We are further in a position now to calculate with I_n known from (**85**) and (**86**) the flux values for both the primary and secondary member. This has been done in Figs. 35 and 36 for a case with

$$\rho = 30 \text{ deg.}$$

It is evident from Fig. 35, which is plotted for a case of relatively high rotor resistance that the rotor resistance not only causes a variation in the size of the rotating field but also a variation in its speed relative to the stator. Fig. 36 showing the same case with the field plotted against the secondary surface shows how the field runs at times ahead of the secondary and subsequently falls back, completing such a cycle in the time $\alpha = \pi$. The combination of the variation in size and the running ahead and falling back of the field with regard to the secondary induces the voltage in the rotor, which is required to drive the rotor currents over the rotor resistance. The dotted line for $\alpha = 75$ deg. in Fig. 35 shows the maximum field interlinking with the center coil of the tertiary winding, and indicates that the tertiary voltage is shifted less than 90 deg. against the primary counter e. m. f. and different in size therefrom. The irregular field speed with regard to the primary can be seen by comparing the values of

v giving the angle of space travel with the corresponding time angle α of the same curve; it will be seen, for instance, that the field travels 39 space degrees during the first 30 time degrees, etc. The variation in the field size is indicated by the line connecting the crest values of the field, and it will be seen that

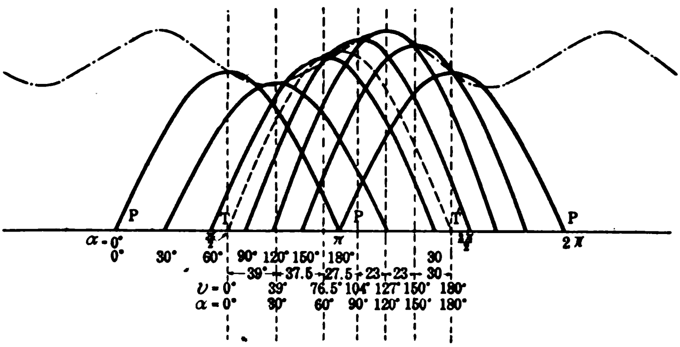

FIG. 35

this curve has double line frequency. In normal machines, the influence of the resistance is very much smaller than indicated in these figures and especially, in case of the sizes used for phase converters it is negligible at no-load, with regard to its influence upon the field sizes and currents, although the phase shifting

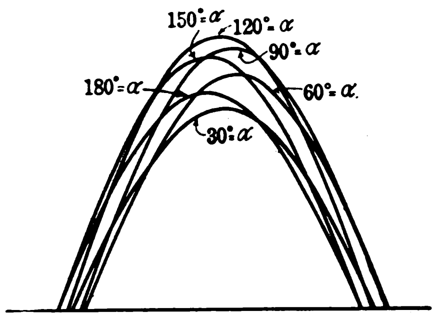

FIG. 36

effect upon the tertiary voltage is appreciable in most cases. In small single-phase induction motors, it is, however, necessary to consider the resistance if exact results for the currents are desirable.

The tertiary voltage can now also be easily determined. Since we know the laws for the stator flux distributions, we merely

need to find the total flux for each tertiary coil by adding all fluxes within the coil. By finding from this $\frac{d\,\varphi_t}{d\,\alpha}\ n_z$ we get the voltage for each coil and subsequently the total voltage by a simple integration of the individual coil voltages.

Equation (**87**) previously derived gave the flux for any stator coil an angle z away from the center of the primary phase belt. The tertiary winding has its maximum turns at the line $Y\,Y'$ Fig. 22, that is, for $z = \frac{\pi}{2}$ and the turns for a coil an angle z away from $x\,x'$ are, therefore,

$$n_z' = \frac{n_p}{2} \sin z\,d\,z$$

By combining this with $\frac{d\,\varphi_{z'}}{d\,\alpha}$ as found from (**87**) we obtain therefore,

$$\frac{d\,\varphi_{z'}}{d\,\alpha} = e_z' = \frac{n_p}{4} \sin z\,d\,z \Big[2\,\varphi \sin(\alpha - Z)$$

$$+ \frac{1}{2} I_n\,r_n\,\big(2\cos(\alpha + \rho + z) - 2\cos(\alpha + \rho - z)\big)\Big] \quad (\mathbf{99})$$

The total tertiary voltage follows from this by integrating between the limits $z = 0$ to $z = \pi$ which gives

$$e_t = \frac{n_p}{4} \Big[-\varphi \left(\frac{1}{2} \sin\ (\alpha - 2\,z) + z \cos \alpha \right)$$

$$+ \frac{1}{2}\ I_n\,r_n \left(\frac{1}{2} \cos(2\,z - \alpha - \rho) - z \sin(\alpha + \rho) \right.$$

$$\left. - \frac{1}{2} \cos(2\,z + \alpha + \rho) - z \sin(\alpha + \rho) \right) \Big]$$

$$e_t = -\frac{\pi}{4}\ n_p\,[\varphi \cos \alpha + I_n\,r_n \sin(\alpha + \rho)] \quad (\mathbf{100})$$

It will be seen that the tertiary voltage consists of a vector equal and at right angle to the primary voltage plus an out-of-phase vector proportional to the secondary ohmic drop. In the case assumed in Figs. 35 and 36, the tertiary voltage is larger than the primary and shifted against it.

The influence of resistance in the primary winding is taken

into account, the same as in any other a-c. apparatus, and, therefore, does not need to be discussed here.

The influence of the leakage reactances can be taken care of in the same way as the resistances with the only difference that the out-of-phase relation of the leakage reactance drop is taken care of in equation (**78**) which gives an equation

$$\frac{d\,\varphi_{n\,i}}{d\,\alpha} = I_n\,x_n \cos\left(2\,\alpha + \epsilon + \rho - \frac{\pi}{2}\right)$$

where x_n is the secondary leakage reactance. Otherwise, the procedure will be the same as outlined in connection with the secondary resistance.

The influence of leakage reactance alone can, however, be taken care of in a much simpler way, by the following consideration.

With zero resistances and zero losses, there will be no phase displacements in either the primary or secondary currents, as found under Case No. 5, and, therefore, only the size of these currents will be changed by the presence of leakage reactance. Let us assume a primary leakage coefficient of σ_p and a secondary leakage coefficient of σ_s. This means that, if a certain magnetomotive force in the secondary, for instance, induces a total flux φ_s, a part $\sigma_s\,\varphi_s$ of the total flux follow the leakage path, while the remaining part $\varphi_s\,(1 - \sigma_s)$ goes across the gap to the stator; similar conditions apply to the primary.

Assume in Fig. 37 the line $x\,x$ to go through the center of the primary phase belt and the line $y\,y$ through the center of the tertiary phase belt.

We found that at the time $\alpha = \frac{\pi}{2}$, the primary m. m. f. is zero, while the secondary m. m. f. sets up a field with the center along $x\,x$. If vector I_s represents the local position and size of the secondary m. m. f. for $\alpha = \frac{\pi}{2}$, the same vector φ_g may be assumed to represent the flux sent across the gap by this m. m. f. This flux cuts the tertiary winding on the stator, and, therefore, represents the tertiary flux φ_t in size.

Since according to our previous definition the flux $\varphi_t = \varphi_s\,(1 - \sigma_s)$ we find the total secondary flux vector

$$\varphi_s = \frac{\varphi_t}{1 - \sigma_s} \qquad (\mathbf{101})$$

With zero secondary resistance we know this flux to be constant and rotating with synchronous speed. It may, therefore, be represented by the vector $\varphi_s' = \varphi_s$ at the time $\alpha = 0$. The secondary m. m. f. represented by $I_s' = I_s$ acts at that time in demagnetizing direction, as shown by vector I_s'. The secondary leakage fluxes being induced by the secondary currents only are

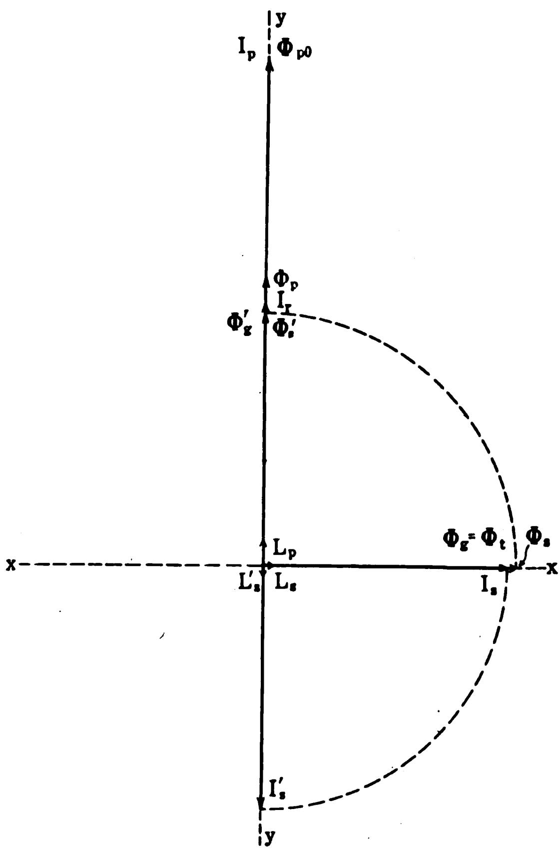

FIG. 37

of course in the direction of these currents and may be represented by the vector

$$L'_s = \varphi_s' \times \sigma_s \qquad (102)$$

If L_s is the secondary leakage flux acting in negative direction and φ_s' the resultant secondary flux, we must have a flux

$$\varphi_0' = \varphi_s' + L_s \qquad (103)$$

cross the air gap into the secondary core. In order to send such flux across the gap, we need a resultant m. m. f. of I_r represented by the same vector. The primary m. m. f. follows therefore as the difference of I_r and I_s' and is represented by I_p.

The primary leakage flux produced by this m. m. f. is found from the imaginary primary flux φ_{po} to be

$$L_p = \sigma_p \times \varphi_{po} \tag{104}$$

Adding this to the gap flux φ_g' we obtain the total primary flux φ_p.

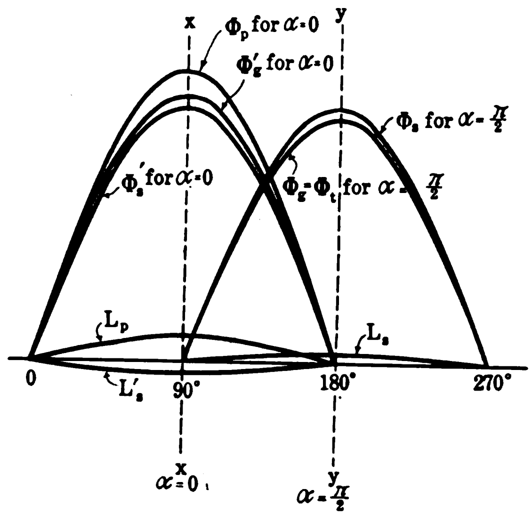

FIG. 38

By making the proper substitutions, we get

$$\varphi_p = \varphi_t \left[\frac{1 + \sigma_s}{1 - \sigma_s} + \sigma_p \left(1 + \frac{1 + \sigma_s}{1 - \sigma_s} \right) \right] = \varphi_t K_2 \tag{105}$$

Since in all but cases of exceptionally high leakage $\frac{1 + \sigma_s}{1 - \sigma_s}$ can be set approximately equal to $1 + 2\,\sigma_s$, we can write

$$\varphi_p = \varphi_t \,(1 + 2\,\sigma_p + 2\,\sigma_s + 2\,\sigma_s\,\sigma_p)$$

or if

$\sigma_p = \sigma_s = \sigma$, where σ = average leakage coefficient for one member.

$$\varphi_t = \frac{\varphi_p}{l + 4\,\sigma + 2\,\sigma^2} \tag{106}$$

The value $2\sigma^2$ is usually negligible in practise and therefore

$$\varphi_t = \frac{\varphi_p}{1 + 4\sigma} \quad \frac{\varphi_p}{K_2} \tag{107}$$

Fig. 38 shows the fluxes given by vectors in Fig. 37 as they are actually distributed in the machine.

The equations for the current follow from the same considerations and the following simple calculation.

In order to produce an air gap flux φ_g, we need a primary current

$$I_p = \frac{\varphi_g}{2\,n_p}\,\frac{K}{K_l} \qquad \text{(See equation 68)}$$

and a secondary current

$$I_n = \frac{\pi}{4}\quad\frac{\varphi_g}{n_s}\quad\frac{K}{K_l} \qquad \text{(See equation 69A)}$$

If we find from these the values for φ_g and equate them, we obtain the following relation between primary and secondary currents:

$$I_p = I_n\,\frac{2}{\pi}\quad\frac{n_s}{n_p} \tag{108}$$

The secondary current is

$$I_n = \frac{\pi}{4}\quad\frac{\varphi_g}{n_s}\quad\frac{K}{K_l} = \frac{\pi}{4}\quad\frac{K}{K_l}\quad\frac{\varphi_p}{n_s}\quad\frac{1}{K_2} \tag{109}$$

(See equation (107) for φ_g.)

Reflecting this into the primary winding, we get by utilizing (108) an equivalent current of

$$I_{pe} = \frac{1}{2}\quad\frac{K}{K_l}\quad\frac{\varphi_p}{n_p}\quad\frac{1}{K_2} \tag{110}$$

In order to send the flux φ_g' across the gap, we need a resultant current

$$I_r = \frac{\varphi_g'}{2\,n_p}\quad\frac{K}{K_l}$$

where $\varphi_{g'}$ follows from (103)

to

$$\varphi_{g'} = \varphi_p - \sigma_p\,I_p\,\frac{K_l}{K}\,2\,n_p$$

Now we know that I_p must be the sum of I_{e} and I_r, therefore,

$$I_p = \frac{1}{2}\quad\frac{K}{K_l}\quad\frac{\varphi_p}{n_p}\quad\frac{1}{K_2} + \frac{\varphi_p}{2\,n_p}\quad\frac{K}{K_l} - \sigma_p\,I_p$$

or

$$I_p = \frac{\varphi_p}{2\,n_p} \quad \frac{K}{K_l} \quad \frac{1 + \frac{1}{K_2}}{1 + \sigma_p} = \frac{\varphi_p}{n_p} \quad \frac{K}{K_l} K_3 \quad \textbf{(111)}$$

We may assume approximately

$$1 + \frac{1}{K_2} = 2 - 4\,\sigma = 2\,(1 - 2\,\sigma)$$

if we further set

$$\frac{1 - 2\,\sigma}{1 + \sigma_p} = 1 - 3\,\sigma$$

we get

$$I_p = \frac{\varphi_p}{n_p} \quad \frac{K}{K_l} \, (1 - 3\,\sigma) = \frac{\varphi_p}{n_p} \quad \frac{K}{K_l} \, K_3 \quad \textbf{(111 A)}$$

It will be seen from comparison of (**110**) and (**69A**), that the secondary currents are the same with and without leakage except for the factor $\frac{1}{K_2}$, which, in normal machines is somewhat smaller than 1.

Similarly, a comparison between (**111**) and (**67**) shows that the primary currents are the same with and without leakage, except for the factor K_3, which, in normal machines, is somewhat smaller than 1.

We have so far considered leakage and resistance separately. An exact consideration of the two combined gives rather complicated expressions without giving an appreciably greater degree of correctness, than is obtained by first considering the resistance only and subsequently modifying the currents with the factors $\frac{1}{K_2}$ in case of the secondary, and K_3 in case of the primary. A lengthy exact derivation of the combined effect may therefore, be omitted here.

All through the previous considerations, it has been assumed that the rotor runs synchronous. In practice, a very small slip is caused by the torque required to overcome bearing and windage friction. This causes small currents of the slip frequency in the rotor in addition to those found from our calculations. These low-frequency currents are, however, at no-load so small that they are of no practical importance whatsoever.

CASE No. 14

Primary Winding Distributed in Slots, Short-Circuited Secondary Winding in Slots, (Squirrel-Cage or Individual Coils Short-Circuited) Resistance and Leakage Reactance Taken into Account

It is evident from the foregoing that an exact consideration of the influence of resistance and leakage reactance in case of any but the simple sinusoidal distribution of the primary winding leads to altogether impracticable amounts of calculation. It has already been pointed out, however, that with windings distributed into slots the presence of resistance and leakage reactance is beneficial with regard to the elimination of the higher harmonics in the currents and that it is, therefore, permissible in most practical cases to neglect the influence of the slots upon the primary current wave form in all but extreme and undesirable designs. While the presence of resistance and leakage reactance is beneficial with regard to the currents, it must be realized, however, that the smoothing out of the current waves is obtained at the expense of the field form for the resultant field. If we have, therefore, for instance cases with few slots per pole which would call for marked current peaks without leakage reactance and resistance, the reduction of such current peaks caused by the presence of leakage reactance will result in higher harmonics for the resultant field form and may with the loaded motor lead to certain counter torques at certain low speeds resulting in dents in the speed-torque curve frequently observed in practise.*

Whatever higher harmonics in the current waves are not fully eliminated by the leakage reactance will usually result in increased effective current values and ohmic losses which, in themselves, may or may not be sufficient to show up in practical tests of commercial machines. Furthermore, the harmonics may on account of their high frequency cause very appreciable eddy losses in heavy copper conductors often used in larger machines. Large no-load losses otherwise unaccountable for can often be traced to this cause.

Any departures from the primary sinusoidal winding distribution made necessary in practise by the fact that the windings have to be distributed in winding belts, as shown in Fig. 24, with definite steps instead of being graduated according to a sine

*NOTE: This is not the only cause for dents in speed-torque curve but only one of many causes. A previous footnote has already mentioned that variation in the permeability of iron, bad distribution of resistance in the rotor, etc., may cause undesirable conditions along this line.

law may have effects similar to those just discussed in connection with the influence of the slots. The harmonics caused thereby in the currents are usually, however, of a much lower order than those caused by the teeth, and, therefore, the smoothing out effect of the resistance and leakage reactance will be much smaller and in most practical machines almost negligible. A practical method for determining the no-load currents rather closely consists, therefore, in the determination of the currents by the methods and formulas given under Case No. 6 and by subsequently modifying the currents thus obtained, for the influence of the resistance and leakage reactance through the introduction of the correcting factors as found in connection with the sinusoidal distribution in Case No. 13. A similar procedure will give good results with regard to the tertiary voltage of the phase converter.

The presence of secondary resistance, especially in squirrel-cage windings, as well as the presence of leakage reactance, both of which interfere to a certain extent with the formation of ideal field forms may, on account of this latter fact, introduce a certain amount of differential leakage which is otherwise impossible. It is, therefore, advisable to allow in practical machines for a small amount of differential leakage in the calculation.

Case No. 15

Primary Winding Distributed in Slots, Secondary Winding of the Slip-Ring Type Distributed in Slots, (i. e., Secondary Windings with a Small Number of Phases with Distributed Coils of Each Phase Connected in Series)

Space does not permit to be given here the complete treatment of this case which is rather involved, but a few essential points may be mentioned without giving a full proof for the statements made. With the star-connected three-phase winding frequently used in secondaries, an additional fundamental condition has to be met besides those previously considered; namely, the sum of all currents flowing at any instant towards the star point must be zero. As long as the primary winding has approximately a sinusoidal distribution thereby calling for sinusoidal current waves in the secondary, this condition is naturally fulfilled as in any true three-phase system with sinusoidal waves. In such a case, we may, therefore utilize the results obtained in connection with Cases No. 5 and 13 with regard to the primary currents and the tertiary voltages. The secondary currents follow directly from the following consideration: We have found for zero

resistance and leakage reactance in connection with Case No. 5, that the entire resultant field is at times set up by the secondary alone. We have further found that the magnetomotive force of the secondary is constant. We can, therefore, conclude from the combination of these two facts that the magnetomotive force of the secondary alone must be at all times sufficient to set up a field which is equal in size to the resultant field. Since the secondary is a three-phase winding, its currents must, therefore, be the same as the magnetizing currents in the primary of a three-phase motor with the same field and the same winding arrangement. In other words, the secondary current of a three-phase winding of a single-phase motor with zero resistance and leakage can be determined rather closely from the formulas used for the primary magnetizing current of a polyphase induction motor; still assuming, of course, that the primary distribution is sinusoidal. The effect of resistance and leakage reactance can subsequently be again taken into account by introducing the modifying factors found under Case No. 13. For delta connected and other polyphase secondary windings, the fundamental condition is somewhat different but the conclusions as so far reached apply as well.

With primary distributions not being sinusoidal, a large multitude of different conditions may apply. In a great many cases the tendency for higher harmonic currents in the secondary is materially reduced as compared with the short-circuited (squirrel cage) winding. With the latter, it was possible for each coil or conductor to individually adjust its current along the lines discussed. With a number of distributed coils connected in series, this is no longer possible and with proper slot relation between primary and secondary, there is a tendency to replace each high current peak of the individual coils by a larger number of smaller peaks in the phase belt. This is the same action as previously described in connection with the primary. For this reason, we find in a great many commercial machines that oscillograms of the secondary currents closely approach a sine curve even though the windings are located in slots and depart a certain amount from a sinusoidal distribution. On the other hand, we may find cases in which the special condition applying to our present case cause, in combination with the other conditions, rather erratic current waves.

The previously mentioned tendency for eliminating harmonics in slip ring secondary windings is again obtained at the expense

of the resultant field form. For this reason, we may again have superimposed rotating fields and corresponding dents in the speed-torque curve; furthermore, the differential leakage may be appreciable in case of slip-ring secondaries.

CONCLUSIONS

FIELDS AND MAGNETOMOTIVE FORCES

The actually existing main field in a single-phase induction machine running light is the resultant of magnetomotive forces furnished by the primary and secondary windings. By assuming the magnetomotive forces of only one of these members existing while those of the other members are assumed to be zero, we obtain imaginary fields which may be called primary field if only the primary magnetomotive force is assumed to exist, and the secondary field if only the secondary magnetomotive force is assumed to exist. All machines have, regardless of the primary winding distribution and the primary field form, a strong tendency to form a resultant field of sinusoidal space distribution rotating at no-load with practically the same speed as the rotor, *i. e.*, with synchronous speed relative to the primary. With an infinite number of secondary slots and with zero resistance and leakage reactance, the space distribution of the resultant field is exactly sinusoidal and the speed of the field is zero relative to the rotor and synchronous relative to the stator no matter what the primary field form may be. With a secondary winding having individually short-circuited coils or conductors embedded in a limited number of slots (usually squirrel-cage windings), the values of the average densities of the individual secondary teeth are also constant and follow a sine law, giving thereby a local distribution for the resultant field of a step form with the middle of each step located on a sine wave as shown in Fig. 15; this is still on the assumption of zero resistance and leakage reactance. These ideal field conditions are in practise slightly disturbed by the usual amounts of resistances and leakage reactances of the windings. The true sinusoidal field distribution is preserved only in case of a sinusoidal distribution of the primary winding and with infinite number of secondary slots. The presence of leakage reactance causes, however, even under these assumptions, slight fluctuations of double frequency in the size of the air-gap field. The presence of rotor resistance also causes such fluctuation in size as well as certain variations in the speed of the resultant field so that it rotates at times somewhat slower and at times

somewhat faster than the rotor. The influence of leakage reactance upon the air gap field φ_0 is shown in Fig. 38; the influence of rotor resistance upon the resultant field is shown in Figs. 35 and 36, the former showing the position of the fields relative to the primary, and the latter, showing it relative to the secondary. The presence of primary resistance results, as in all a-c. apparatus, in a slight phase displacement and a small change in the size of the flux.

With non-sinusoidal distribution of the primary winding the influence of resistance and leakage reactance is similar to that described in connection with the sinusoidal primary curve. Moreover, it may, however, cause the departure of the resultant field from the sinusoidal space distribution. Such departures are slight in most commercial machines but may be appreciable in case of exceptionally large secondary resistance or large leakage reactances.

With machines of the slip ring type, which usually have a limited number of secondary phases with a number of series-connected phase coils distributed over phase belts, the resultant field may depart more from the sinusoidal distribution than in all other cases.

The size of the resultant flux in single-phase induction machines is, as in most a-c. apparatus, principally determined by the impressed voltage and frequency and the number of primary conductors and their distribution; the influence of the resistance and leakage reactance upon the size of the flux is usually rather small.

The local distribution of the imaginary primary field is naturally governed by the local distribution of the primary winding and the magnetic reluctances of the machine. Except for minor influences in the variation of the reluctances, the primary field is of constant form and stationary relative to the primary winding, but varying in size and direction.

The imaginary secondary field is, in its form and size, at any time governed by the fact that the primary and secondary densities must, together give the densities called for by the previous rules for the resultant field. This means that the secondary field has often very peculiar shapes and varies in form and size with the primary winding distribution and the reluctance of the machine.

The primary and secondary field forms as obtained when neglecting the influence of resistance and leakage reactance are shown:

In Fig. 2 for a concentrated primary winding with a concentrated single phase secondary winding. (See Fig. 1.)

In Figs. 11 and 12 for a concentrated primary winding with concentrated two-phase secondary windings. (See Fig. 6.)

In Fig. 20 for a concentrated primary winding with short circuited secondary having an infinite number of slots.

In Fig. 23a for a primary winding with sinusoidal distribution and a secondary winding with an infinite number of slots. (See Fig. 22.)

In Fig. 27a for a primary winding evenly distributed over 90 deg. and a secondary winding with an infinite number of slots.

The secondary field travels with double synchronous average speed relative to the secondary in a direction opposite to the mechanical rotation of the secondary. It, therefore, travels with synchronous speed relative to the primary winding opposite to the relative mechanical rotation of the secondary.

Primary Magnetizing Currents

The primary magnetizing current has a sinusoidal wave with a sinusoidal voltage impressed upon the machine and an infinite number of secondary slots and phases, regardless of the local distribution of the primary winding. The maximum and effective values of these primary sinusoidal currents are, however, governed to a large extent by the distribution of the primary winding. This is brought out by formulas given under Cases No. 5 and 6. These formulas while applying exactly only under the assumptions made, are correct within one or two per cent for most standard machines if the turns of each primary slot are assumed to be distributed between the centers of the two adjacent teeth.

With a non-skewed slot construction, a slotted primary and a short-circuited secondary with a limited number of secondary slots (squirrel-cage rotor) the curve of the primary magnetizing current may materially depart from a sine curve. Every time a secondary slot coincides with a primary slot a current peak is caused in the primary magnetizing current. These peaks will increase the effective value of the currents above those found in the previous formulas and are furthermore liable to cause appreciable eddy losses in heavy conductors. Some extreme cases of such current peaks are shown in Figs. 3, 7A, 9A and 16A corresponding to windings shown in Figs. 1, 6 and 13. These current peaks will be the more marked, the larger the number of primary and secondary slots which coincide locally at any one time. By keeping such number of coinciding slots small, the departure of the primary current from a sine curve can be made

negligible so that the formulas can be applied with a sufficient degree of accuracy.

The leakage reactance of the machine is of material assistance in eliminating current peaks and it may, therefore, be found that, under otherwise equal conditions, the magnetizing current is slightly smaller in machines with large leakage.

The fundamental frequency of the primary currents is of course, the same as the line frequency; whatever higher harmonics exist are usually odd harmonics. If the rotor speed is slightly less than synchronous, the location of the higher harmonics on the fundamental wave changes periodically with the slip.

Outside of the influences previously mentioned, resistances and leakage reactances of the motor tend to decrease the primary magnetizing currents as can be seen by comparing the formulas found under Cases No. 5 and 13.

In motors with phase wound slip ring secondaries, most of the previous remarks apply, except that the tendency for higher harmonics in the primary current is usually somewhat smaller than in the case of squirrel-cage rotors.

Secondary Magnetizing Currents

With synchronously rotating secondary, the fundamental wave of the secondary currents has double line frequency. With sinusoidal primary winding distribution no higher harmonics exist as indicated in Fig. 23 which shows a number of secondary currents.

Any departure from a sinusoidal distribution of the primary winding will cause the secondary currents to depart materially from a sinusoidal curve and furthermore, cause the currents in different secondary conductors to be different from each other. If the secondary speed is slightly different from synchronous speed, the current wave in each secondary coil changes its shape and size periodically with the slip. The two waves of a secondary current cycle are usually different from each other indicating the presence of even harmonics which are quite large in a great many cases.

Figs. 3, 7B, 7C, 9B, 9C, 16B and 21 show secondary current waves for primary windings concentrated into a mathematical point and having no leakage corresponding to arrangements shown in Figs. 1, 6 and 13. These cases are, of course, extreme, and in practise, impossible. Figs. 25, 26, 27, 28 and 29 show secondary current waves of primary field forms shown in con-

nection with these figures. The heavy line 1, 2, 3, 4, etc., of Fig. 30c shows the influence of the fact that the primary winding is distributed over a number of slots upon the secondary currents, in case of a secondary having a much larger number of slots than the primary. Fig. 34c shows the secondary current for the same case except that the number of secondary slots is assumed to be about the same as the number of primary slots. Fig. 31 shows again a similar case, except that wide open slots are assumed in the primary with the number of secondary slots much larger than the number of primary slots.

It is evident from these figures that the secondary currents are subject to a large number of variations. While, therefore, the simple formulas derived for a sinusoidal primary distribution may give a rough approximation for the secondary currents in single-phase machines, it should be realized that the marked higher harmonics are liable to increase not only the effective current value and the ohmic losses, but may also cause very appreciable eddy losses in the heavy conductors often employed in squirrel-cage windings, as well as in the heavy section end rings.

As in the case of the primary currents, the leakage reactance will again be beneficial in reducing the higher harmonics. Both resistance and leakage reactance also tend to decrease the fundamental wave, as can be seen by comparison of Cases No. 5 and 13.

With slip ring secondaries having phase belts, the tendency of higher harmonics in the secondary is usually much smaller than in short-circuited secondaries, although erratic wave shapes may be obtained in extreme cases.

Tertiary Voltages in Phase Converters

The tertiary voltage of a phase converter is sinusoidal if the primary voltage is sinusoidal and the secondary has an infinite number of phases. In case of a short circuited secondary (squirrel cage) with a limited number of secondary slots the tertiary voltage has a step shape similar to that shown in Figs. 17 and 18 with the center of the steps located on a sine wave. With a distributed tertiary winding of proper choice of tooth pitch and winding distribution, the size of the steps can be reduced so that the tertiary voltage approaches more closely a sine curve. Neglecting the resistance and leakage reactance, the tertiary voltage equals the primary voltage with equal number of turns

if the secondary has an infinite number of slots. With a limited number of slots, the tertiary voltage decreases slightly with the number of secondary slots, as indicated in curve No. 19; this influence is the same as usually considered in connection with the zig-zag leakage, in reality it is here caused by the departure of the resultant flux from the sinusoidal wave shape. With the speed slightly different from synchronism, the resultant wave shape of the field varies periodically with the slip which also causes periodic variations in the higher harmonics of the tertiary voltage, without, however, affecting the effective value of the tertiary voltage.

The presence of slot and end connection leakage reactance causes a further difference between the primary and tertiary voltages, in the same direction as that caused by the zig-zag leakage or the difference in wave shape. The presence of resistance in the windings not only affects the amplitude of the tertiary voltage as compared with that of the primary, but also disturbs the 90 deg. phase relation in two-phase converters and the corresponding relation in converters wound for other numbers of phases.

General

It is realized that the rather abstract methods used in this paper are not always best adapted to explain the various phenomena in the most simple manner. It is obvious, however, that after the facts have been definitely established by such methods, it will be possible to work out other treatments of the same phenomena; these can be made both simpler to understand, and at the same time correct, by keeping continuously the results derived from this and similar papers in mind. The various methods of assuming fields of oppositely rotating direction appear to be especially advantageous in this connection.

APPENDIX I

Fig. 6 represents a phase converter with a single concentrated primary coil $P P'$ and a single concentrated tertiary coil $T T'$. The rotor is provided with a two-phase winding consisting of two concentrated coils 1 and 2 displaced 90 deg. against each other. The current and fluxes applying to these coils may be designated by i_1, i_2, φ_1 and φ_2, respectively. The four quadrants of the rotor are marked A, B, $-A$ and $-B$, and the fluxes carried by these quadrants are φ_A, φ_B, $-\varphi_A$, $-\varphi_B$. The densities B are

indicated by similar subscripts. Other assumptions are similar to those in case of Fig. 1.

Assume again, that coil 1 coincides with P at the time $\alpha = \gamma$ we know that, the flux of coil 1 has the constant value

$$\varphi_1 = \varphi \cos \gamma \tag{1}$$

The coil 2 coincides with P at a time $\frac{\pi}{2}$ earlier than coil 1, at the time $\alpha = \gamma - \frac{\pi}{2}$, so that it has the constant flux value

$$\varphi_2 = \varphi \cos \left(\gamma - \frac{\pi}{2} \right) \tag{2}$$

For any value $x = 0$ to $x = \frac{\pi}{2}$ corresponding to the time $\alpha = \gamma$ to α to $\gamma + \frac{\pi}{2}$ we have the following equations;

$$\varphi_i = \varphi_a + \varphi_b' + \varphi_c \tag{3}$$

$$\varphi_1 = - \varphi_a + \varphi_b + \varphi_c \tag{4}$$

$$\varphi_2 = - \varphi_a - \varphi_b + \varphi_c \tag{5}$$

By adding (**5**) and (**3**), subtracting (**4**) from (**3**), and (**5**) from (**4**), and by introducing the values from (**1**) and (**2**), we find

$$\varphi_a = \frac{\varphi}{2} (\cos \alpha - \cos \gamma) \tag{6}$$

$$\varphi_b = \frac{\varphi}{2} \left(\cos \gamma - \cos \left(\gamma - \frac{\pi}{2} \right) \right) \tag{7}$$

$$\varphi_c = \frac{\varphi}{2} \left(\cos \alpha + \cos \left(\gamma - \frac{\pi}{2} \right) \right) \tag{8}$$

The densities are, therefore,

$$B_a = \frac{K}{2} \varphi \frac{\cos \alpha - \cos \gamma}{x} \tag{9}$$

$$B_b = \frac{K}{2} \varphi \frac{\cos \gamma - \cos \left(\gamma - \frac{\pi}{2} \right)}{\frac{\pi}{2}} \tag{10}$$

$$B_c = \frac{K}{2} \varphi \frac{\cos \alpha + \cos \left(\gamma - \frac{\pi}{2} \right)}{\frac{\pi}{2} - x} \tag{11}$$

Under consideration of the current directions shown in Fig. 6, we have the following relations for the currents, assuming that n_1 and n_2 are the numbers of turns in coil 1 and 2.

$$B_a = K_1 (i_p n_p - i_1 n_1 + i_2 n_2) \tag{12}$$
$$B_b = K_1 (i_p n_p + i_1 n_1 + i_2 n_2) \tag{13}$$
$$B_c = K_1 (i_p n_p + i_1 n_1 - i_2 n_2) \tag{14}$$

By adding and subtracting these and introducing the values from (9), (10) and (11) with $x = \alpha - \gamma$ we obtain

$$i_p = \frac{K\varphi}{4 K_l n_p}\left[\frac{\cos\alpha - \cos\gamma}{\alpha - \gamma} + \frac{\cos\alpha + \cos\left(\gamma - \frac{\pi}{2}\right)}{\frac{\pi}{2} - \alpha + \gamma}\right]$$

$$i_1 = \frac{K\varphi}{4 K_l n_1}\left[\frac{\cos\gamma - \cos\left(\gamma - \frac{\pi}{2}\right)}{\frac{\pi}{2}} - \frac{\cos\alpha - \cos\gamma}{\alpha - \gamma}\right]$$

$$i_2 = \frac{K\varphi}{4 K_l n_2}\left[\frac{\cos\gamma - \cos\left(\gamma - \frac{\pi}{2}\right)}{\frac{\pi}{2}} - \frac{\cos\alpha + \cos\left(\gamma - \frac{\pi}{2}\right)}{\frac{\pi}{2} - \alpha + \gamma}\right]$$

The tertiary flux is now

$$K\varphi_t = B_b x + B_c\left(\frac{\pi}{2} - x\right) - B_a x - B_b\left(\frac{\pi}{2} - x\right)$$
$$= - B_a x + B_b\left(2x - \frac{\pi}{2}\right) + B_c\left(\frac{\pi}{2} - x\right)$$

or by introducing the values for the densities

$$\varphi_t = \frac{\varphi}{2}\left[2\cos\left(\gamma - \frac{\pi}{2}\right) + \frac{4x}{\pi}\left(\cos\gamma - \cos\left(\gamma - \frac{\pi}{2}\right)\right)\right]$$

By determining $\dfrac{d\,\varphi_t}{d\,\alpha}$ we get

$$e_t = \frac{2\,\varphi}{\pi}\left(\cos\gamma - \cos\left(\gamma - \frac{\pi}{2}\right)\right)$$

Similarly, we find for value $x = \dfrac{\pi}{2}$ to $x = \pi$ corresponding

to the time $\alpha = \gamma + \dfrac{\pi}{2}$ to $\alpha = \gamma + \pi$

$$\begin{aligned}
\varphi_i &= \varphi_d + \varphi_e + \varphi_f \\
\varphi_1 &= -\varphi_d - \varphi_e + \varphi_f \\
\varphi_2 &= \varphi_d - \varphi_e - \varphi_f
\end{aligned}$$

$$\varphi_d = \frac{\varphi}{2}\left(\cos\alpha + \cos\left(\gamma - \frac{\pi}{2}\right)\right)$$

$$\varphi_e = -\frac{\varphi}{2}\left(\cos\gamma + \cos\left(\gamma - \frac{\pi}{2}\right)\right)$$

$$\varphi_f = \frac{\varphi}{2}\,(\cos\alpha + \cos\gamma)$$

$$B_d = \frac{K}{2}\,\varphi\,\frac{\cos\alpha + \cos\left(\gamma - \frac{\pi}{2}\right)}{x - \frac{\pi}{2}}$$

$$B_e = -\frac{K}{2}\,\varphi\,\frac{\cos\gamma + \cos\left(\gamma - \frac{\pi}{2}\right)}{\frac{\pi}{2}}$$

$$B_f = \frac{K}{2}\,\varphi\,\frac{\cos\alpha + \cos\gamma}{\pi - x}$$

$$\begin{aligned}
B_d &= K_1\,(i_p\,n_p - i_1\,n_1 - i_2\,n_2) \\
B_e &= K_1\,(i_p\,n_p - i_1\,n_1 + i_2\,n_2) \\
B_f &= K_1\,(i_p\,n_p + i_1\,n_1 + i_2\,n_2)
\end{aligned}$$

$$i_p = \frac{K\,\varphi}{4\,K_1\,n_p}\left[\frac{\cos\alpha + \cos\left(\gamma - \frac{\pi}{2}\right)}{\alpha - \gamma - \frac{\pi}{2}} + \frac{\cos\alpha + \cos\gamma}{\pi - \alpha + \gamma}\right]$$

$$i_1 = \frac{K\varphi}{4K_l n}\left[\frac{\cos\alpha + \cos\gamma}{\pi - \alpha + \gamma} + \frac{\cos\gamma + \cos\left(\gamma - \frac{\pi}{2}\right)}{\frac{\pi}{2}}\right]$$

$$i_2 = \frac{K\varphi}{4K_l n_2}\left[\frac{-\cos\gamma + \cos\left(\gamma - \frac{\pi}{2}\right)}{\frac{\pi}{2}} - \frac{\cos\alpha + \cos\left(\gamma - \frac{\pi}{2}\right)}{\alpha - \gamma - \frac{\pi}{2}}\right]$$

$$K\varphi_t = B_e\left(x - \frac{\pi}{2}\right) + B_f(\pi - x) - B_d\left(x - \frac{\pi}{2}\right) - B_e(\pi - x)$$

$$\varphi_t = \frac{\varphi}{2}\left[+4\cos\gamma + 2\cos\left(\gamma - \frac{\pi}{2}\right) - \frac{4x}{\pi}\left(\cos\gamma + \cos\left(\gamma - \frac{\pi}{2}\right)\right)\right]$$

and

$$\frac{d\varphi_t}{d\alpha} = -\frac{2\varphi}{\pi}\left(\cos\gamma + \cos\left(\gamma - \frac{\pi}{2}\right)\right) = e_t$$

To be presented at the 339th Meeting of the American Institute of Electrical Engineers, Pittsburgh and New York, April 9 and 12, 1918.

A PHYSICAL CONCEPTION OF THE OPERATION OF THE SINGLE-PHASE INDUCTION MOTOR

BY B. G. LAMME

ABSTRACT OF PAPER

This paper covers a method of studying the actions of the single-phase induction motor, which the writer has found to be very convenient from the educational standpoint. It is based upon the assumption of two equal and oppositely rotating primary magnetomotive forces combined with a synchronously rotating secondary m. m. f., such as would be produced by direct current excitation. It follows that there is a resultant rotating primary field just as in the polyphase motor, while in the secondary there are two currents, one of low frequency, corresponding to the polyphase motor, and the other of nearly double the primary frequency. Diagrams and descriptions are given to illustrate the magnetomotive forces and fluxes, showing how, among other conditions, two oppositely rotating fields of unequal value may be possible.

The next step is a consideration of e. m. f. generation by two oppositely rotating fields, showing how both must be taken into account. The effects upon the counter e. m. f. and excitation, of the reduction or suppression of one field is shown. This illustrates, in a simple manner, why the excitation on single-phase must be practically the same as on polyphase at full speed and falls to one-half value at standstill.

The full-load conditions are next considered. A comparison is made between a two-motor unit, consisting of two similar polyphase motors coupled together and connected for opposite rotation, and the straight single-phase induction motor. Various discrepancies are pointed out between the resultant action of the two-motor unit and the single-phase. Modifying conditions are then taken into account which remove the discrepancies. This is followed by a considerable amount of test data which illustrate the principles and actions described in the paper.

THE underlying principles and the operating characteristics of the polyphase induction motor are so well understood that it is found desirable to consider the single-phase induction motor, simply as a special case of the polyphase. On this basis the single-phase motor must be considered primarily as a rotating-flux machine.

Starting with the old assumption that a single-phase alternating magnetic field may be considered as being made up of two constant fields, each of half the peak value of the single-phase field and rotating at uniform speed in opposite directions, then

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if the single-phase flux distribution is of sine shape and varies sinusoidally in value, it may be replaced, or represented, by two sine-shaped fields of constant value rotating in opposite directions. This is the simplest case and allows a relatively easy explanation of many single-phase problems. However, when the flux distribution, or field form, due to the single-phase winding, is other than of sine shape, then the oppositely rotating components cannot be considered as of sine shape, but will assume certain varying forms as they rotate, the resultant of each instantaneous pair always giving the single-phase field corresponding to that instant.

As other than sine-shape fields tend toward complications in the physical conception of the single-phase induction motor actions, and lead more or less into the mathematical conception, the following analysis will be limited essentially to sine-shape distributions.

As a starting point and to show reasons for certain later analysis, let us assume a single-phase induction motor operating at no-load, full speed, with its polyphase secondary winding short-circuited. The single-phase primary field, of assumed sine shape, is considered as made up of the two sine-shape equal components of constant value, and of half the peak value of the single-phase field, and rotating synchronously in opposite directions. One of these fields is traveling in the same direction as, and slightly faster than, the rotating secondary. The slip of the secondary with respect to this field is of the same nature as in the ordinary polyphase motor. As the machine is carrying no load the secondary current corresponding to this rotating field is very small, being just large enough to overcome the rotational losses in the motor itself, and its frequency is equal to the slip frequency due to the forward field component.

As there is an assumed backward flux or field component of equal value, the rotating secondary winding cuts this at almost double the frequency of the line. Stated exactly, the sum of the backward and the forward frequencies, in the secondary winding, is equal to exactly double the frequency of the primary supply system. The secondary winding cutting the backward field at this high frequency tends to generate a very considerable e. m. f. and, with the winding closed on itself, short-circuit currents will flow, which tend to damp out or suppress the flux which causes them. This secondary current will rise until its magnetizing effect is practically equal and opposite to the magnetomotive

PLATE IX.
A. I. E. E.
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[LAMME]

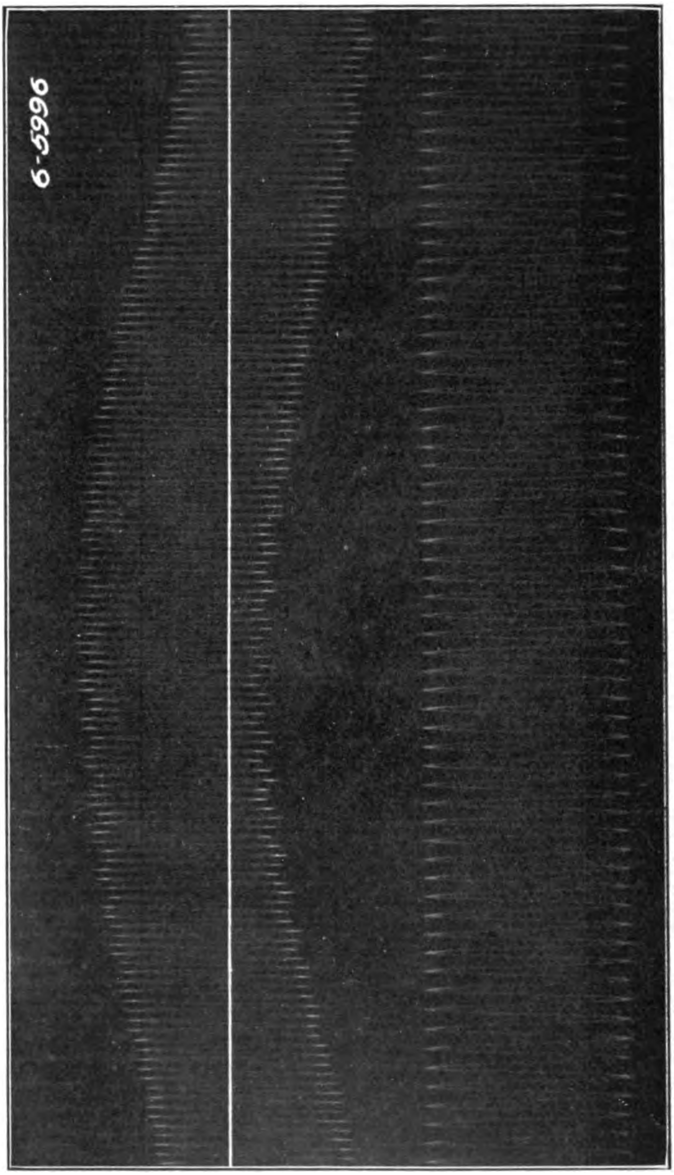


FIG. 1

force which produces the backward field, which thus becomes almost zero in value. Consequently there are two distinct sets of secondary currents flowing, one of very small value and of a frequency corresponding to that of the forward rotation, and the other of very much larger value and of almost double the line frequency. Actual tests of the secondary circuit of a single-phase induction motor at small load, taken with an oscillograph, Fig. 1, show both of these currents as above described.

Magnetomotive Forces and Magnetic Fluxes

It is seen from the preceding that, right at the beginning of our analysis, a new condition is encountered, namely, the introduction of a secondary opposing magnetomotive force which reacts on one of the primary field components and practically neutralizes it. Also, there is a mixture of magnetomotive forces and magnetic fields, which is liable to lead to confusion. Obviously the introduction of the opposing secondary magnetomotive force rotating synchronously with the backward component of the primary introduces some entirely new features. Therefore, before going any further with the above method, it is desirable to set aside for awhile the viewpoint of two equal oppositely rotating fields and begin with a preliminary study of the magnetomotive forces and the magnetic fields resulting from them.

It may be mentioned that while the assumption of two oppositely rotating component fields, in place of a single-phase field, is well known and has been used quite frequently, the corresponding analysis, from the viewpoint of magnetomotive forces, apparently has been but little used. When magnetomotive forces, instead of magnetic fluxes, are considered, then the single-phase primary magnetomotive force, fixed in position, can be replaced by two equal components of constant value, such as would be developed by direct current, each of half the peak value of the single-phase, and rotating at synchronous speeds in opposite directions.

Returning again to our analysis, let us consider two fundamental magnetomotive forces, namely, a primary single-phase one, fixed in position and varying sinusoidally and a secondary one of constant value, of half the peak value of the primary which rotates synchronously in one direction and which is in opposition to the primary in the position where the two coincide.

Let us assume that the primary single-phase magnetomotive force is split into its two equal oppositely rotating components,

then the results may be illustrated as in Figs. 2, 3, 4, and 5. In Fig. 2, C and D represent the two components forming the single-phase magnetomotive force A. At the position chosen, C and D are of equal value and coincide in position and polarity, B, which represents the secondary magnetomotive force, is also of half the peak value of A, but is of opposite polarity. It, therefore, neutralizes one of the components C or D, thus leaving a resultant of half the peak value of A.

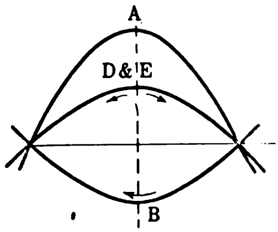


FIG. 2

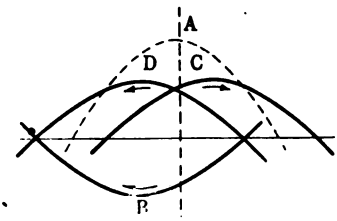


FIG. 3

In Fig. 3, the component D has shifted thirty degrees to the left, while C has shifted an equal distance to the right. The secondary magnetomotive force B is shifted thirty degrees to the left, thus neutralizing D and leaving only the component C.

In Fig. 4, D and B are shifted sixty degrees to the left, while C is shifted sixty degrees to the right. In the same way, in Fig. 5, B and D have shifted ninety degrees to the left and C has shifted a corresponding amount to the right.

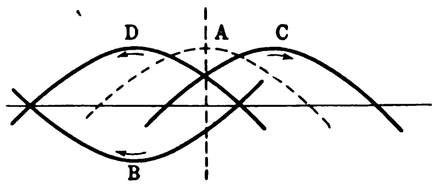


FIG. 4

Thus from the above it is seen that a single-phase magnetomotive force, fixed in position and varying sinusoidally, and a constant magnetomotive force of half the peak value of the single-phase, which is in opposition at the point of coincidence of position, and which rotates synchronously in either direction, will give a resultant constant magnetomotive force, rotating in the opposite direction, but which is of the same polarity as the single-phase magnetomotive force at the position of coincidence.

In other words, a single-phase magnetomotive force, fixed in position, and an opposing constant one of half the peak value rotating in either direction, will give a resultant rotating magnetomotive force equivalent to that of a polyphase induction motor.

As a continuation of the above, the resultant magnetomotive force *C* could be replaced by a magnetic field or flux, resulting from such magnetomotive force. If this magnetic field is plotted to the same scale as the magnetomotive force which produces it, then *C*, in Figs. 2 to 5, can represent a magnetic field. This field will be constant in value and of half the peak value of the field which the single-phase magnetomotive force alone would set up.

Thus according to Figs. 2, 3, 4 and 5, by the introduction of an "opposing" magnetomotive force, equal in value to one of the component magnetomotive forces of the single-phase and rotating synchronously with it, one of the two components of the magnetic field can be suppressed and only the other component left,

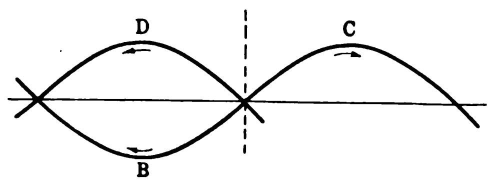


Fig. 5

the resultant is thus a rotating magnetic field, just as in the polyphase induction motor.

However, a further modification of this should be considered. Assuming again, that the single-phase primary magnetomotive force is replaced by its two equal rotating components, as in Figs. 2 to 5, then by the addition of an opposing magnetomotive force, similar to *B* in the same figures, but of *less value than the component D*, then the resultant of this opposing magnetomotive force and the component *D* is a reduced magnetomotive force of the same polarity as *D*. There will then remain two magnetomotive forces, each of constant value, one of half the peak value of *A* and the other of some smaller value, depending upon the opposing force *B*. These two rotating magnetomotive forces can, therefore, set up two oppositely rotating fields of *unequal* value. These are illustrated in Figs. 6, 7 and 8.

In Fig. 6, *B* is assumed at some less value than the component *D*. The resultant of *D* and *B* is shown as *E*. Therefore, at this

position C and E represent the two resultant magnetomotive forces and the two component fields. In Fig. 7, the conditions are shown for thirty degrees shift and here again E and C represent the two fields. In Fig. 8 the shift is for sixty degrees.

Thus by the introduction of a constant "opposing" magnetomotive force of less than either of the components of the single phase, two oppositely rotating fields of unequal value may be set up. As extreme cases of this, if the constant opposing magnetomotive force is made zero in value, the magnetic field corresponding to its position and rotation will rise to the full value of the oppositely rotating field; and, on the other hand, if the constant opposing magnetomotive force is made half the peak value of the single phase, the correspondingly rotating field becomes zero. Both of these cases are in accordance with the earlier assumptions.

The above conditions of the single-phase primary magneto-

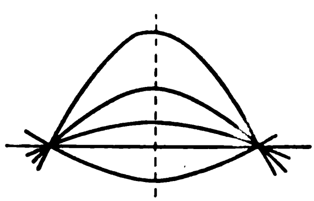


Fig. 6

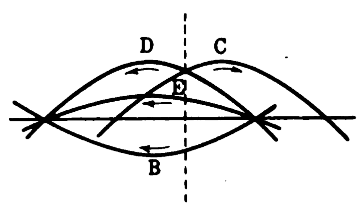


Fig. 7

motive force and a constant secondary one, in opposition, which may be of half the peak value, or some less value down to zero, and which rotates synchronously in one direction, resulting in two magnetic fields which may be of equal or unequal value, and which rotate synchronously in opposite directions, all form essential parts in the physical conception or visualization of the actions of the single-phase motor which will be given below.

It should be observed that in the above method of considering the production of a rotating field in the single phase induction motor, the two primary components of the single-phase magnetomotive force and the secondary damping magnetomotive force *all rotate synchronously*, and such rotation is independent of the speed of the secondary core. In some methods of considering the single-phase induction motor problem, the single-phase primary winding is assumed to generate a magnetomotive force in the secondary which, by rotation of the core, is carried around until it generates a second magnetic field or flux at right angles to the

original primary flux, thus giving the equivalent of a polyphase magnetic field. However, the above method does not involve such method of treatment.

It should also be recognized that the foregoing analysis only covers no-load conditions and that with the addition of load new conditions are brought in to the problem. These, however, will be brought out later, for the no-load conditions require further consideration, especially as regards the generation of the primary counter e. m. f. by the above described rotating fields. As already shown, there may be a single magnetic field rotating synchronously, or there may be two component fields of equal value rotating in opposite directions, or there may be intermediate conditions of oppositely rotating fields of unequal value, depending upon the value of the damping or opposing secondary magnetomotive force.

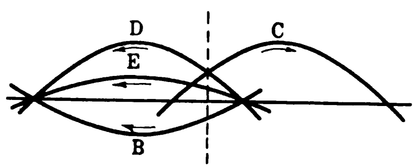


FIG. 8

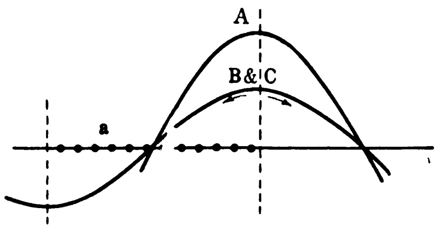
COUNTER E. M. F. GENERATION AND EXCITATION

Considering next the counter e. m. f. generated in the primary, we should first look into the e. m. f. conditions produced by two oppositely rotating fields of equal values. If the secondary circuits are open, the two component fields are both present and are concerned in the generation of the counter e. m. f. This is true whether the secondary is stationary or is rotated at full speed. If, however, the secondary is closed upon itself, then when running at speed, one of the component fields is practically damped out and the other must generate the entire primary counter e. m. f. Thus, two entirely different conditions are encountered, depending upon whether the secondary is open or closed. To explain this properly, some further analysis is required, as follows:

In the first place, it may be stated that the e. m. f., produced in the primary winding by *cutting* its two component fields, is the same as that generated by the single phase sine shape field, varying sinusoidally and acting on the primary winding as in a

transformer. Herein lies a simple illustration of the equivalence of the transformer and the flux cutting methods for calculating e. m. fs. In Figs. 9, 10 and 11, are shown several positions of the two oppositely rotating fields and their relation to the primary winding.

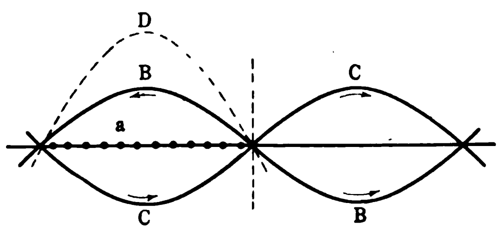
In Fig. 9 is shown the magnetic flux, or field, *A*, which is set up by a primary winding *a*. This winding, of course, would



Fɪғ. 9

require a tapered distribution to give such a field. This is mentioned incidentally as it has no direct bearing upon the explanation, except from the mathematical standpoint.

Assuming the single-phase field at its maximum or peak value, then, at this instant, the two component fields, *B* and *C*, each of half the peak value, will coincide both in position and polarity. From the transformer method of calculation, the e. m. f. gener-



Fɪɢ. 10

ated at this instant, in the winding, will be zero, as the rate of change of the flux is zero. Also from the flux cutting method, the e. m. f. in the primary winding will be zero, for, as is evident from the figure, each belt or group of the primary winding is cutting fields which have equal positive and negative areas or values.

Considering next the conditions in Fig. 10, in which the two rotating components have traveled ninety degrees. The fields

are shown as *B* and *C*. It is evident that the resultant of these two fields is zero in value, that is, the single-phase field is passing through its zero value, and, accordingly, is generating the maximum e. m. f. by the transformer method. Also, considering component *B* of the rotating fields, obviously, by the cutting method it is generating maximum e. m. f. in the winding *a*. Also, component *C* is generating maximum e. m. f. in winding *a*. However, as one of these fields is positive in this position and is traveling in one direction, while the other field is negative and is rotating in the opposite direction, the two e. m. fs. will be in the same direction, and thus will be added. Thus, from the figure, this position will give the maximum e. m. f. in the winding by the cutting method. It can be shown by calculation that this maximum value is the same with either the cutting or the transformer methods of considering e. m. f. generation.

This shows that both of the component fluxes must be taken

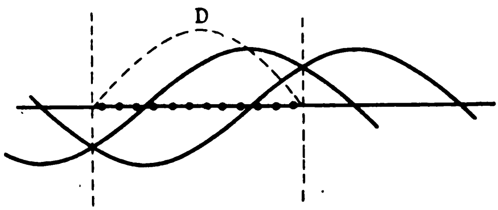


FIG. 11

into account in generating the total primary e. m. f., and if either component is decreased in value or suppressed, the total e. m. f. generated in the winding will be decreased correspondingly, unless the other component is increased a corresponding amount.

Fig. 11 is simply a continuation of the conditions of Figs. 9 and 10, in showing an intermediate position of the component field. The result is the same as if the two fields were momentarily replaced by the field *D*.

According to the above analysis, to produce a given counter e. m. f. in the primary, with one of the component fields damped out, the other component must be doubled in value. It was shown before that in the single phase induction motor, running at full speed with no load, the backward field is practically damped out by the secondary current. Thus with only the forward component field remaining, either the counter e. m. f. will be halved or the forward flux component must be doubled, the latter being the case. This means, in turn, that the primary

magnetomotive force must be doubled in value. In other words, suppressing one of the two rotating field components results in doubling the no-load excitation of the motor. Furthermore, doubling the magnetomotive force of the primary and thus doubling the forward component of the field also doubles the backward component, which, in turn, is suppressed by doubled secondary current. The above conditions of doubled excitation is on the basis of sine flux distribution. With other distributions the same result holds approximately, but not exactly, due to conditions involving the shape of the field.

It is evident from the above that, with the secondary circuits open, the excitation required is of constant value regardless of the speed of the rotor core and windings; also when running at speed, the primary excitation is doubled as soon as the secondary circuit is closed. However, it is not obvious, on first consideration, that even with the secondary circuits closed the primary excitation falls to half the full speed value, when the motor is brought to standstill. This involves load conditions which will be treated later, but nevertheless this feature may be brought out at this time. The explanation lies in the fact that at rotor standstill the damping action of the secondary current will be exerted equally on both the forward and backward components of the primary field, so that necessarily these must be maintained at equal value, and, by the above analysis, this requires but half the excitation, compared with the no-load full-speed condition where the backward field is practically completely suppressed.

Load Conditions

When the single-phase induction motor is loaded, the total input current can be considered as made up of two components, namely, the no-load (practically all magnetizing) and the load current. This latter is simply the increased current in the primary due to the load and does not entirely represent energy. This load current, being single-phase, may be represented by two equal oppositely rotating magnetomotive forces in the primary of the motor, just as in the case of the no-load current. The fields which these two magnetomotive forces tend to set up are both practically suppressed by two equivalent *secondary* magnetomotive forces rotating in opposite directions. The forward secondary component corresponds to the secondary load magnetomotive force in the polyphase motor and the interaction between this magnetomotive force and the forward primary field

develops torque just as in the polyphase motor. The backward component, at first thought, would appear to develop an opposing torque, corresponding in value to that of the polyphase motor at approximately 200 per cent slip. This, however, is not the case, for at this slip the ordinary polyphase motor takes an excessive primary current tending to develop a large magnetic field, which is suppressed by a correspondingly large secondary magnetomotive force. In the single-phase induction motor, however, the primary backward rotating magnetomotive force component, due to the load current, can be only of the same value as the forward. This fact must be borne in mind as it is a very important factor in the later analysis.

To illustrate the characteristics of the single-phase induction

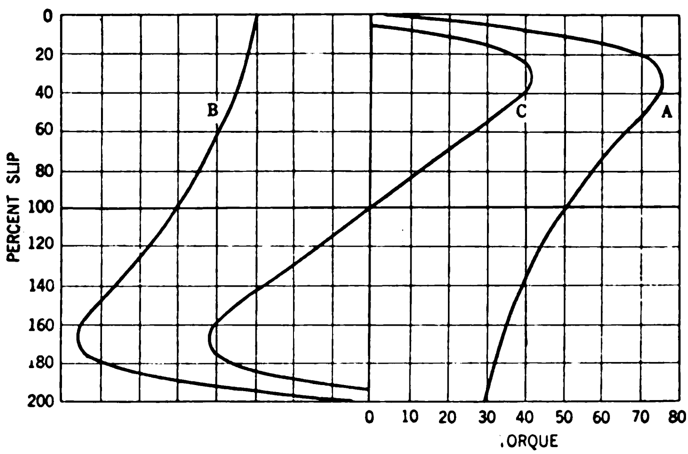


FIG 12

motor, it may be compared with the action of two polyphase induction motors rigidly coupled together, and connected to the line to give opposite rotations. Such a set or unit has certain characteristics which are so similar to those of the usual single-phase induction motor that on first consideration one would assume them to be identical. However, a more careful study of the individual operating conditions shows that the similarity is only a general one, and a number of decided discrepancies are found.

The characteristics of the above two-motor unit and the single-phase motor may be compared as follows:

(1) The speed torque characteristics of the two motors of the polyphase unit may be represented by *A* and *B* in Fig. 12 and

their resultant by curve *C*. According to this latter curve, the resultant torque is zero at standstill, and a slight change in speed in either direction will give an effective torque tending to speed up the unit in whichever way it is started. This, therefore, corresponds to the well known starting characteristics of the single-phase motor.

(2) It may also be seen that the maximum torque the unit develops is materially less than that of either of the two component motors. This fact is also consistent with single-phase motor operation compared with the same machine on polyphase.

(3) At full speed, according to this resultant curve, the slip

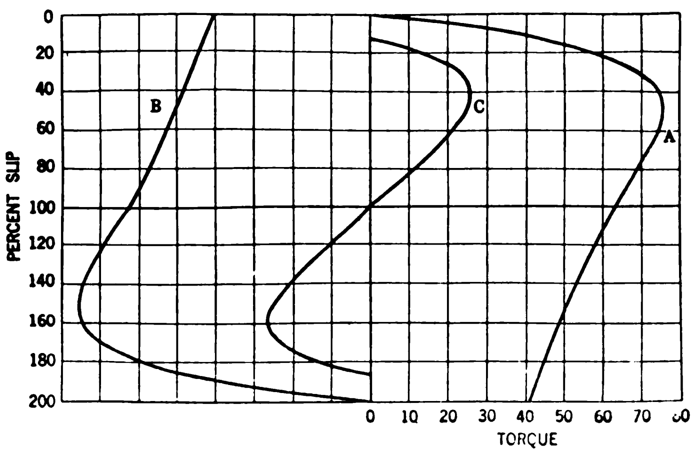


FIG. 13

for a given torque is very much larger than that of the corresponding polyphase motor. This is not true of the single-phase motor and herein lies one of the discrepancies in this method of illustrating the operation.

(4) It is well known that in the polyphase motor the maximum torque it can develop, with constant voltage applied, is independent of the secondary resistance; while, in the single-phase motor, in general, an increase in the secondary resistance will decrease the maximum torque and a decrease will have the opposite effect. This may be illustrated by repeating the curves of Fig. 12 with modified secondary resistance in the two component motors. In Fig. 13 the secondary resistance is increased and in Fig. 14 is decreased relatively to that of Fig. 12. The

resultant speed-torque curves for the three figures show that the maximum torques are materially affected by the secondary resistance. The same holds true for the single-phase induction motor.

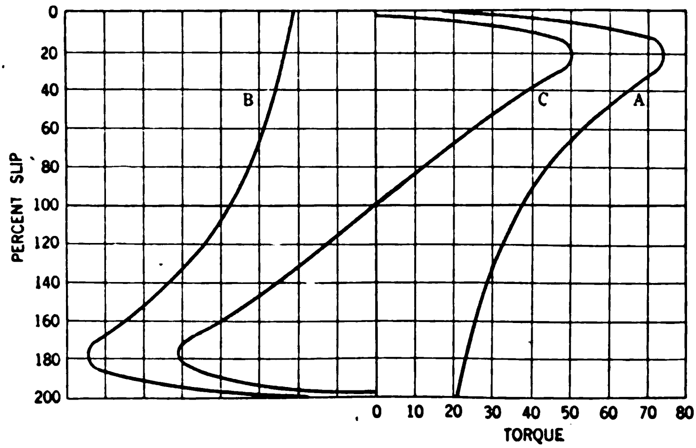


Fig. 14

(5) However, this method of illustrating the characteristics of the single-phase motor torque fails when the conditions of secondary resistance is such that the maximum polyphase torque

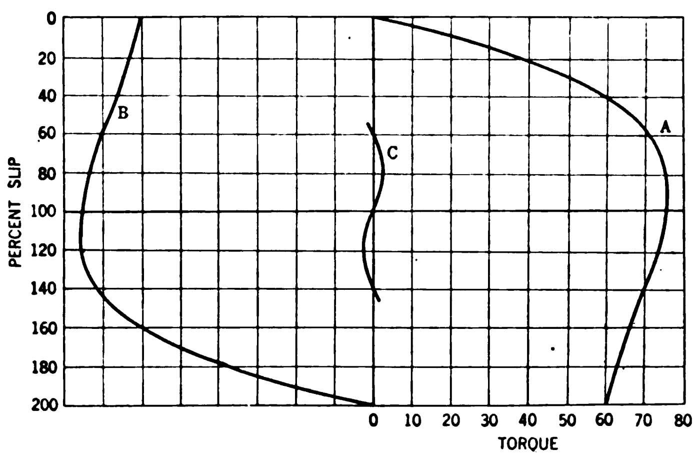


Fig. 15

is developed at about 100 per cent slip. Fig. 15 illustrates this. From this speed torque curve it appears that the unit has a very low resultant torque, but this is not the case in the single-phase

induction motor, for with a polyphase motor developing its maximum torque at 100 per cent slip, the same machine on single-phase will give a very considerable maximum torque. Here again is a discrepancy which the assumed equivalent arrangement does not cover properly.

(6) In Fig. 16, the current-torque curve *D*, for the component motors in the above figures, is shown. This indicates plainly what a wide discrepancy there is between the currents taken by the primaries of the two motors when running at speed. For example, at a given speed *a*, the current taken by the forward rotating motor is *b*, while *c* represents the current taken by the backward motor. Obviously, the current taken from the line, which is the resultant of *b* and *c*, is much greater than that required to produce the resultant torque and the power factor of such a unit must necessarily be very poor. However, such is not the case with the single-phase motor, for the inputs and the power factors are not greatly different from those of polyphase motors of the same capacity. Herein lies a radical difference between the single-phase motor and the above assumed unit.

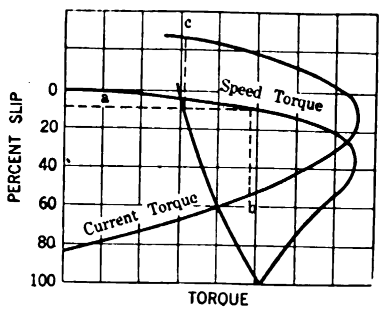


FIG. 16

(7) Another difference between such a unit and the true single-phase motor lies in the no-load or magnetizing input. Obviously, the combined magnetizing components for the two motors will be twice as great as for a single machine, whereas, in the single-phase motor the magnetizing input is practically the same as in the corresponding polyphase machine. Here is another pronounced discrepancy.

It is evident from the above that while this method of illustrating the action of the single-phase motor by means of two polyphase motors, coupled for opposite rotation, is in the right direction, some special modifying conditions must be introduced to account for the discrepancies. The action of this two-motor unit, therefore, will be followed up further, with the introduction of certain modifications derived primarily from consideration of certain characteristics of the single-phase induction motor itself.

In the first place, curves *A*, *B* and *C* of Fig. 12 were based upon equal and constant e. m. fs. applied to the terminals of both

motors. That this is not a correct assumption can be determined from the operating conditions in the single-phase motor. From the analysis of the component rotating fields it was shown that at full speed the backward component was practically damped out by a secondary magnetomotive force, thus leaving only the forward component, which then rose to practically double value in order to generate the required e. m. f. However, at standstill, the secondary winding holds the same rotational relation with respect to both component fields and, therefore, neither field can be damped out more than the other. Consequently, at standstill, both component fields are equal in value and the counter e. m. f. of the primary is generated by the two oppositely rotating fields, instead of a single one of double value

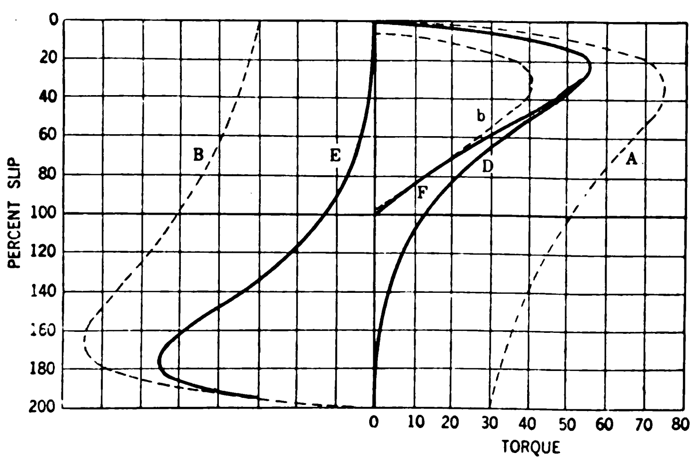


FIG. 17

as is the case at full speed. Therefore, at standstill, the forward field is of only half the value of the full speed field. This corresponds to the operation of the polyphase motor at half field strength, that is, *with half the primary voltage applied*, thus requiring one-quarter the magnetizing input. The same voltage condition applies also for the backward component at zero speed.

It would appear, therefore, that in the unit composed of two polyphase motors coupled together, the voltage applied to the terminals of the forward motor should be at practically full value at synchronous speed and should fall to half value at standstill or 100 per cent slip, and should have practically zero value at 200 per cent slip. Then assuming, as a first approximation, that the decrease in voltage from full speed to 200 per cent slip

is a straight line law, new speed torque curves, corresponding to Fig. 13, but with the torques decreasing as the square of the voltage, can be illustrated as in Fig. 17. Here curves *A* and *B* correspond to Fig. 12, while *D* and *E* correspond to the above proportionate reductions in voltage. The resultant *F* of these latter curves is also shown.

This new resultant *F* is similar in general shape to *C* of Fig. 12, but indicates some quite different characteristics. For instance, at the higher speed values it coincides quite closely with the polyphase speed torque curve, which is actually the case in the single-phase motor. In the second place, with high secondary resistance, as shown in Fig. 15, the speed-torque curves are modified as in Fig. 18, which shows both the former characteristic

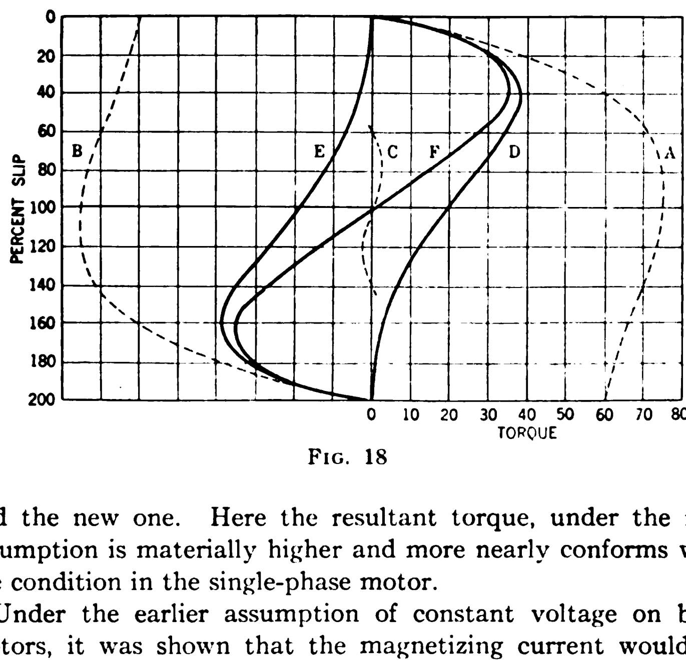


FIG. 18

and the new one. Here the resultant torque, under the new assumption is materially higher and more nearly conforms with the condition in the single-phase motor.

Under the earlier assumption of constant voltage on both motors, it was shown that the magnetizing current would be twice as great as in the single-phase motor. On this new assumption, however, at full speed, with practically full voltage on one motor and zero voltage on the other, the total magnetizing current will be only half as great, and will approximate that of one motor alone, and, therefore, that of the single-phase motor.

Furthermore, under the new assumption, the current taken by the primary of the backwardly rotating motor is quite small at high speed and, therefore, the resultant current taken from the

line is not excessive and is more nearly consistent with actual single-phase motor conditions.

Thus, with this new condition of reduced terminal voltage with reduction in speed, practically all the conditions of the single-phase motor are met, except possibly from the quantitative viewpoint. The two-motor combination thus serves as a very good illustration. There is, however, one further condition ***which must be rigidly met*** if the new curves are to be reasonably exact, namely, ***the primary currents taken by the two motors must be equal,*** for, as shown in the early part of this analysis, the forward and backward rotating components of the primary current in the single phase induction motor are equal at all times. Consequently to duplicate this condition, the primary e. m. fs. im-

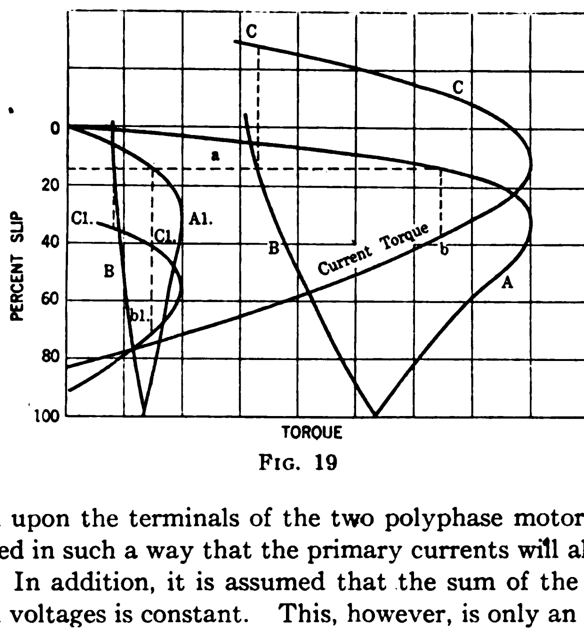


FIG. 19

pressed upon the terminals of the two polyphase motors should be varied in such a way that the primary currents will always be equal. In addition, it is assumed that the sum of the two impressed voltages is constant. This, however, is only an approximation.

The next step is to determine what is the actual law of voltage variation which will satisfy the above conditions of current and voltage. A ready means for obtaining this lies in the speed-torque and current-torque curves of the polyphase motor at constant voltage. From the current-torque curve at constant voltage corresponding curves for any other voltage can readily be plotted by varying the abscissae as the square of the voltage and the ordinates directly as the voltage. This is illustrated in Fig. 19. Here A is the polyphase motor speed-torque curve at

constant voltage. B represents the part below the 100 per cent slip line, but turned above the zero speed line for convenience. B can also be considered as the back torque at full voltage, but thrown to the right of the zero torque line for convenience. Curve C represents the primary current for full voltage conditions. Then at a speed a, for example, the primary currents corresponding to the forward and back torque will be b and c respectively.

Assume next that the voltage is halved for both rotations, then the new speed-torque curves will be A_1 and B_1 in which the torques are reduced as the square of the voltage. The new current curve will be C_1. The currents for speed a will now be b_1 and c_1, or half of b and c, as they are varied as the voltage.

The above figure is simply to illustrate the rule for variation of the primary current with the voltage, in the polyphase motor, and does not represent the actual conditions which we are after; for in the above the voltage reductions are the same for both the forward and the back torques. But, according to our former analysis, this condition of equal voltages, for the two rotations, holds only for the 100 per cent slip point. For other speeds the two voltages are reduced unequally, but with the sum of the two approximately constant according to the assumptions.

If, for any speed a, we let x represent the percentage of voltage reduction for the forward torque, then $1 - x$ will represent the corresponding reduction for the back torque. Let I_f be the primary current, corresponding to the forward torque for this speed at full voltage, and I_b the current for the back torque at the same speed and also for full voltage. Then $I_f x$ will represent the primary current at the reduced voltage for the forward rotation and $I_b (1 - x)$ will be the primary current for the back rotation. One of the conditions of our two-motor unit, to make it correspond with the single-phase motor, is that these two primary currents must be equal. Therefore, $I_f x = I_b (1 - x)$, and

$$x = \frac{I_b}{I_f + I_b} \text{ and } (1 - x) = \frac{I_f}{I_f + I_b}.$$

The above allows the determination of the percentage x of full voltage which must apply for each speed between zero and synchronism, when the values of the current I_f and I_b for full voltage are known.

A second method of determining the percentages of voltage

for the two rotations is available when the speed-torque curve of the motor on single phase has been determined, by test or otherwise. By our former assumption this single phase torque is the difference between the speed torque curves for the forward and backward rotations with the respective voltages reduced the proper percentages. These torques for any given speed vary as the square of the terminal voltage. For example, calling T_f the forward torque, at full voltage and speed a, and T_b the back torque, and T_1 the single phase torque for the same voltage and speed, then $T_f x^2 - T_b (1 - x)^2 = T_1$, from which x may be determined, with T_f, T_b and T_1 known.

It would appear from the preceding that, if the assumptions made are anyways close to the actual conditions, this method of analysis shows a means for deriving the single-phase speed-torque curve from the polyphase curves of the same machine. Methods of calculating the primary current and speed-torque characteristics of the polyphase motor have been developed quite completely, so that it is not necessary at this place to give any details of such methods. The accuracy of the methods for calculating the polyphase curves depends almost entirely upon the correct determination of the reactance and saturation constants. All methods for the direct determination of the single-phase speed-torque characteristics also involve the use of corresponding reactance and saturation constants. Therefore, the above method brings in no new and more difficult conditions. The primary object of this paper, however, is not to develop a new method of calculation, but simply to give a better conception of the close relation of the single-phase and polyphase characteristics.

After development of the above method, an attempt was made to check it by applying certain existing test data, but without positive results, although the indications were quite satisfactory. It was discovered that in all the existing test data at the writer's command, where the polyphase speed-torque and current-torque curves has been obtained by actual test, constancy of temperature had been more or less disregarded. The effect of change in the secondary resistance on the polyphase speed-torque curve is to change the slips but not the maximum torque. The difficulty, however, in the polyphase tests available was that apparently the resistance had varied very considerably during the tests, especially at the points of high slip, where the secondary losses were very large. As a result the speed-torque curves

corresponded to those of motors in which the resistance increased as the load and slip increased. As a consequence, the torques below the zero speed line were considerably too large, which meant that in applying these curves to the above method, the back torques were presumably entirely too great, thus apparently introducing errors in the derivation of the resultant single-phase curve.

The effect of these discrepancies are shown in Fig. 20. Here, *A* shows the speed-torque curve as it should be at constant temperature, whereas, *B* shows the curve with the resistance of the secondary increasing with increased slip. The corresponding current-torque curves are also shown. A consideration of these curves would seem to indicate that the resultant single-phase curves derived from *A* and *B* should differ somewhat.

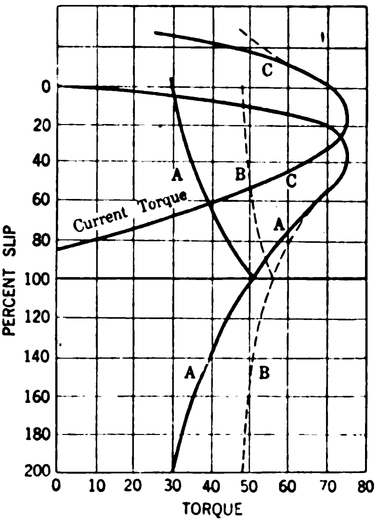


FIG. 20

It was then decided to make a more accurate set of tests on a 10 h.p., 60-cycle four-pole, three-phase motor of the wound-secondary type, so that the secondary resistance could be varied if so desired. It was also decided to obtain a test with two similar motors rigidly coupled together, with their individual primary windings in series, but with their secondaries independent. As already explained, the theory of the foregoing method calls for *equal currents* in the two oppositely rotating fields. This condition is automatically obtained by coupling two primaries in series with each other.* With this arrangement, if the power factors of the two motors were always equal, then it should be equivalent to the method already described. However, these are practically never equal except at the standstill position, although an analysis of the problem shows that the two primary voltages, with this series arrangement, are not greatly out of phase with each other over a very large part of the working range. The writer has not yet sufficiently analyzed the series arrangement

*In reviewing an early draft of this paper, this suggestion, with a number of other most excellent ones, was made by Mr. R. E. Hellmund.

to be sure that it exactly represents all the conditions of the two rotating fields in the single-phase motor, but is inclined to think that such is the case. However, the approximate method developed in this paper lends itself so readily to calculation, that it was considered worth while to check it up carefully by test to see what degree of accuracy could be obtained.

The following series of tests was planned:

(1) Three-phase speed-torque and primary current curves at 220 volts with one motor alone, with its secondary short-circuited on itself.

(2) Single-phase speed-torque and primary current curves on the same motor as (1) at 220 volts and with the secondary short-circuited on itself.

(3) Three-phase speed-torque and primary current curves on the same motor and at same voltage, but with external resistance in the secondary circuits.

(4) Single-phase speed-torque curves under same conditions as (3).

(5) Speed-torque and primary current curves with two similar motors with their primary windings coupled in series, and with the secondaries independently short circuited on themselves, one of these motors to be that used in tests (1) and (4).

(6) Similar tests to (5), but with resistance in the secondaries as in (3).

In carrying out these tests, the torque was measured by a special dynamometer brake, the power absorbing element of which consists of a special separately-excited direct-current machine. Below zero speed, power was supplied to the direct-current machine in order to obtain negative rotation.

Difficulties in obtaining consistent tests, especially at negative speeds, soon developed, due to variations in temperature. With the very heavy currents at low and at negative speeds, the motor would heat so rapidly that all kinds of speed-torque readings could be obtained. Test after test was made and while these would agree very well for the higher speed points where the heating was small, they showed all kinds of inconsistencies for the negative speeds, in particular. The currents for these speeds also showed very wide discrepancies. Eventually it was found that those tests taken with extreme rapidity, and which covered only a comparatively small number of points, would plot in quite reasonable curves above zero speed, so that the writer was enabled thus to obtain quite consistent curves

for both torque and current between 1800 rev. per min. and standstill. Not only were the curves, consistent in themselves but those taken with different secondary resistances were fairly consistent with each other. It then remained to obtain reasonable readings for the negative speeds. Obviously it was wrong to take a large number of test points and then draw an average curve through them, for it is evident that the errors, due to heating, tend to throw the torques and currents to one side of the proper curves. Consequently the correct curves should really be boundary lines rather than averages. It was noted, in particular, that heating did not appear to affect the speed to the same extent as the torque at very large slips, and, consequently, by plotting the current in terms of speed rather than torque, less erratic curves were obtainable, and it was possible to plot speed-current curves which were quite consistent for the different conditions of secondary resistance. Furthermore, from the speed-torque and speed-current curves above the zero line, which appeared to be reasonably correct, as they were consistent with each other, it was possible to derive the constants for the general equations for speed-torque. It was found that such derived equations fitted these curves quite accurately and, moreover, they held the proper relation of constants for both high- and low-resistance secondaries. The various agreements between the calculations and the tests for the higher speeds were such that one could assume that the derived equations were practically correct and that from them the curves for the negative speeds could be plotted with fair accuracy. In this way the curves for the negative speeds were first obtained and it then remained to check them by actual test. Finally a method of testing was tried which appeared to give quite good results. This consisted in setting the apparatus at about the desired speed and torque conditions; then cooling the motor down to the required temperature preparatory to obtaining the desired test, the power was then thrown on and readings obtained in the shortest possible time, five seconds, for instance. Allowing the motor to run, additional readings were obtained at five second intervals. A series of consecutive readings, at definite intervals apart, was thus obtained and plotted in a curve. By extending this curve back to the instant of starting, results were obtained which were undoubtedly quite close to those corresponding to the starting temperatures, and were not only quite consistent with each other, but also plotted very close to the negative exten-

sions of the calculated curves. As a result of a series of tests extending over several weeks, data was obtained which plotted in curves which agreed fairly well with each other throughout.

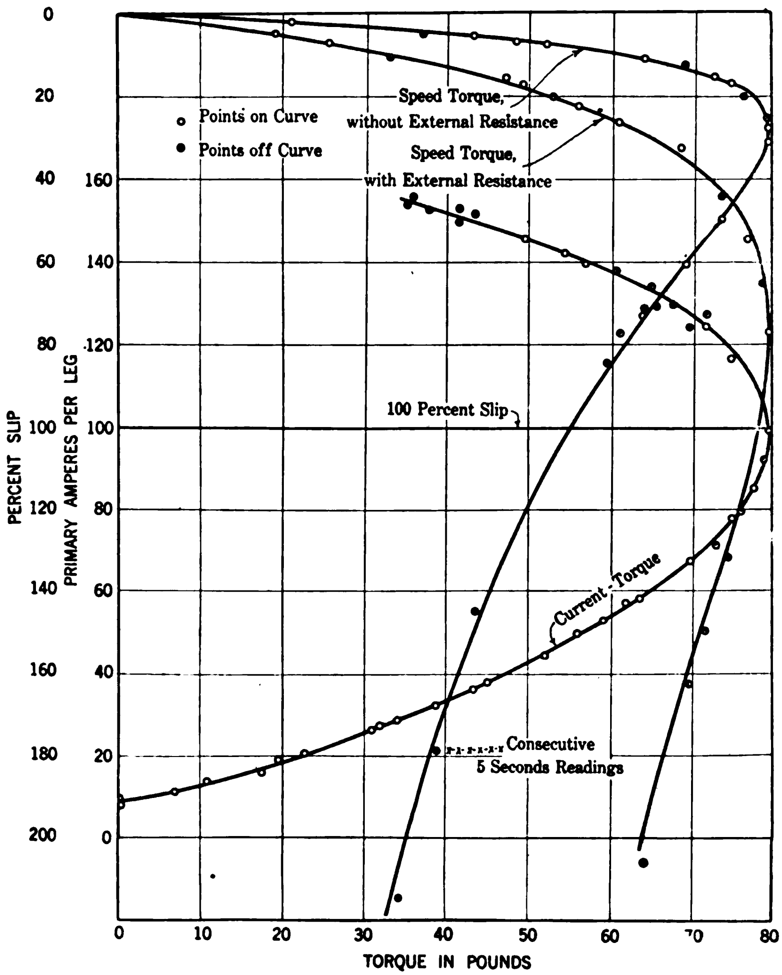


FIG. 21

RESULTS OF TESTS

Polyphase Speed-Torque, Speed-Current and Current-Torque Curves

In Fig. 21 are shown the polyphase speed-torque and primary current both with the secondary short-circuited, and with resistance added. In the speed-torque curves the circled points

represent actual test readings, while the solid line covers the points calculated from the derived equations.

In Table I, covering data on the short-circuited-rotor tests, are shown the forward and back torques and the corresponding forward and back currents for the various speeds between zero and 200 per cent slip, as derived from Fig. 21; also the calculated values of the ratio of voltages, x and $(1 - x)$, by which the forward and back torques should be reduced in order to get the equivalent single-phase speed-torque curve. The corresponding reduced values for the forward and back torques are also given as calculated from the values x and $(1 - x)$. The last column shows the difference between the reduced forward and back torques, which should represent the single-phase torque, according to the foregoing analysis.

TABLE I

Slip		Torque at full voltage		Primary amperes per leg at full voltage		$X =$		Reduced torque		Resultant torque
For positive speeds	For negative speeds	T_f	T_b	I_f	I_b	$\frac{I_b}{I_f+I_b}$	$1-x$	Forward	Back	
0.02	1.98	20.	35.8	19.0	154.8	0.89	0.11	15.8	0.4	15.4
0.05	1.95	41.	36.3	34.0	154.5	0.819	0.181	27.5	1.1	26.4
0.10	1.90	61.7	36.9	55.5	154.0	0.735	0.265	33.3	2.6	30.7
0.15	1.85	71.6	37.7	71.0	153.5	0.684	0.316	33.5	3.8	29.7
0.20	1.80	77.3	38.3	85.0	153.0	0.643	0.357	31.9	4.9	27.0
0.25	1.75	79.4	39.2	96.0	152.5	0.614	0.386	29.9	5.9	24.0
0.30	1.70	79.6	39.9	104.0	152.0	0.594	0.406	28.1	6.6	21.5
0.35	1.65	78.8	40.8	110.0	151.5	0.580	0.420	26.5	7.2	19.3
0.40	1.60	77.6	41.6	113.0	151.0	0.572	0.428	25.4	7.6	17.8
0.50	1.50	74.0	43.6	121.0	150.0	0.554	0.446	22.9	8.7	14.2
0.60	1.40	70.0	45.5	128.0	149.0	0.538	0.462	20.3	9.7	10.4
0.70	1.30	65.9	47.8	133.0	147.3	0.526	0.474	18.2	10.8	7.4
0.80	1.20	62.1	50.0	136.5	145.5	0.516	0.484	16.6	11.7	4.9
0.90	1.10	58.8	52.7	139.5	143.5	0.507	0.493	15.1	12.8	2.3
1.00	1.00	55.5	55.5	141.5	141.5	0.50	0.500	13.9	13.9	0

In Fig. 22 are shown the single-phase speed-torque and current-torque curves with short-circuited secondary, as plotted from Table I, and checked by actual test. The circled dots represent actual test points, while the crosses represent points plotted from the last column in Table I. The agreement of test and calculated values are as close as can really be expected considering the difficulties in obtaining the data, and the possible errors.

Unfortunately, due to the very short time available, it was not possible to make any extended tests on single phase with a view to correcting for temperature. In consequence, the calculated single-phase speed-torque curve, which is on the basis of constant temperature, is compared with tested curves in which no temperature correction has been made. It, therefore, is not known in this case how much of the discrepancy is due to temperature.

In Table II is shown data similar to that of Table I, but for the tests with resistance in the secondary. It will be noted that the resultant of the forward and back torques is considerably lower than in Table I, which is consistent with the fact that in-

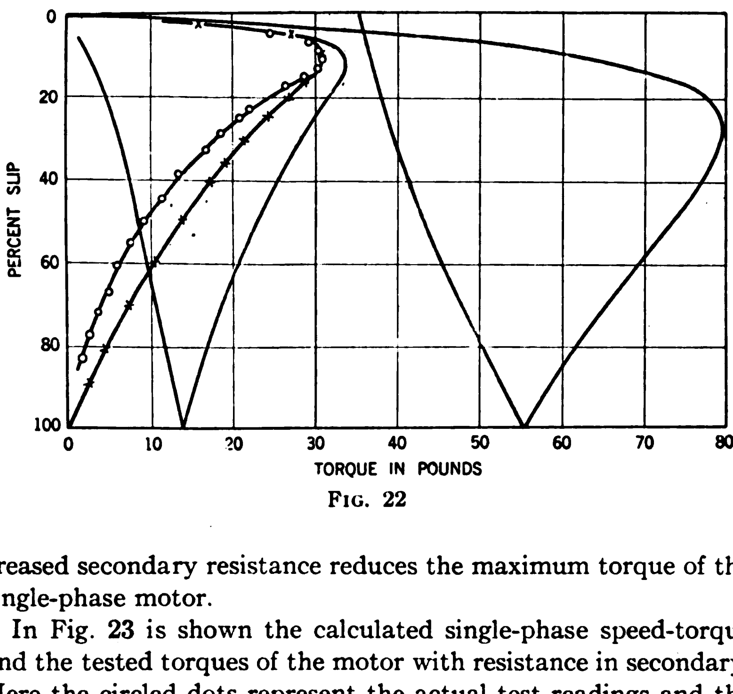


FIG. 22

creased secondary resistance reduces the maximum torque of the single-phase motor.

In Fig. 23 is shown the calculated single-phase speed-torque and the tested torques of the motor with resistance in secondary. Here the circled dots represent the actual test readings and the crosses represent the points obtained from the last column of Table II. The discrepancies are somewhat smaller than in the motor with short circuited secondary. This should be the case, if heating is responsible for any considerable part of the discrepancy, for the currents are relatively smaller.

In order to get a crude idea as to how much of the difference may be due to this feature of temperature, a polyphase speed-

torque test was selected in which no correction had been made for temperature and where the conditions were quite closely comparable with those of the single-phase tests. From the speed-torque and current data of this polyphase test, the resultant single-phase speed-torque curve was calculated, making no attempt at corrections of any sort. This speed-torque curve is represented by the small squares in Fig. 23. This lies much closer to the tested single-phase curve, thus indicating that temperature is possibly an explanation of a considerable part of the discrepancy between the calculations and the tests. This would

TABLE II.

Slip		Torque at full voltage		Primary amperes per leg at full voltage		$X =$		Reduced torque		Resultant torque
For positive speeds	For negative speeds	T_f	T_b	I_f	I_b	$\frac{I_b}{I_f+I_b}$	$1-x$	Forward	Back	
0.02	1.98	8.2	64.3	12.5	134.2	0.915	0.085	6.9	0.5	6.4
0.05	1.95	18.9	64.8	18.0	133.8	0.881	0.119	14.7	0.9	13.8
0.10	1.90	33.3	65.4	28.0	133.0	0.826	0.174	22.5	2.0	20.5
0.15	1.85	41.5	66.1	37.0	132.3	0.781	0.219	27.5	3.2	24.3
0.20	1.80	53.1	66.9	46.0	131.5	0.740	0.260	29.3	4.5	24.8
0.25	1.75	59.8	67.6	53.0	130.8	0.712	0.288	30.3	5.6	24.7
0.30	1.70	65.1	68.4	60.0	130.0	0.684	0.316	30.5	6.8	23.7
0.35	1.65	69.2	69.1	66.0	129.0	0.662	0.338	30.4	7.9	22.5
0.40	1.60	72.2	69.9	71.2	128.0	0.643	0.357	29.9	8.9	21.0
0.50	1.50	76.5	71.4	81.0	125.5	0.608	0.392	28.2	11.0	17.2
0.60	1.40	78.7	72.9	88.0	122.7	0.582	0.418	26.6	12.7	15.9
0.70	1.30	79.6	74.4	94.0	120.0	0.561	0.439	25.0	14.4	10.6
0.80	1.20	79.6	75.9	99.5	118.1	0.542	0.458	23.4	15.9	7.5
0.90	1.10	79.2	77.8	104.0	112.2	0.519	0.481	21.4	18.0	3.4
1.00	1.00	78.9	78.9	108.2	108.2	0.50	0.50	19.7	19.7	0

also indicate that heat effects as referred to in connection with Fig. 20 are not as objectionable as anticipated. However, the writer does not believe that all the discrepancy is due to heating, but considers that this approximate method of dealing with the problem makes the back torque too small. In the arrangement with two motors in series, as mentioned before, the voltages of the two motors will not usually add up directly to give the line voltage, and the motor which represents the back torque, will have a relatively larger percentage of the total voltage than is the case with the above method of considering the problem. This will be considered further under the two-motor tests.

Two Motors in Series

In Table III is shown the test data and the calculations derived therefrom, for two motors with their primaries in series and with their secondaries short-circuited independently. In this test no external resistance was used in the secondaries. Considerable difficulty was encountered in making this test, due partly to bad alignment of the machines, as they were rigidly coupled together. Furthermore, in several of the earlier tests, the effects of temperature were disregarded and all indications were that the secondaries were quite hot during the tests. There was so much discrepancy between the various results that the

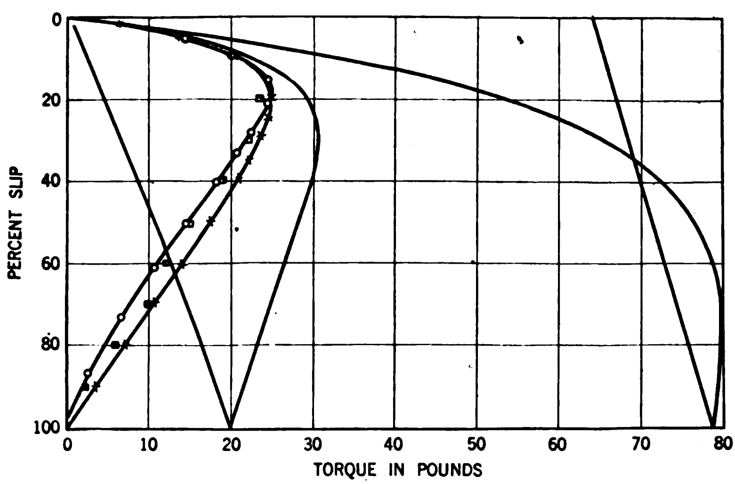


FIG. 23

writer cannot feel sure of the data shown in this table, although it was obtained under quite careful conditions of test.

In the above table the percentage of line voltage applied to each motor is shown. It is of interest to compare these percentages with those shown in Table I. This is illustrated in Fig. 24. This shows that the percentage of voltage on the forward rotating motor is higher at the higher speeds, than in Table I, but is lower at the low speeds. On the other hand, the voltage on the backward-rotating motor is higher at all speeds than in Table I. Thus, the back torque has always a higher value than in Table I. Consequently, with the reduced forward torque at the lower speeds and the higher back torque, the resultant torque

TABLE III.

Speed		Torque corrected to 220 volts	Volts			Ratio of motor to line volts		Polyphase torque at 220 volts		Polyphase torque at reduced voltage		Resultant torque
r. p. m.	Slip		Line	No. 1 motor	No. 2 motor	No. 1 motor	No. 2 motor	Forward	Back	Forward	Back	
300	0.833	1.5	218.5	109.2	110.5	0.506	0.505	61.0	51.4	15.6	13.1	2.5
600	0.667	2.5	217.0	110.9	107.5	0.511	0.495	67.0	47.0	17.5	11.5	6.0
800	0.556	4.9	218.5	115.8	106.8	0.530	0.488	71.5	44.5	20.9	10.6	10.3
1000	0.444	8.3	219.0	118.4	105.0	0.541	0.48	76.0	42.4	22.2	9.8	12.4
1100	0.389	9.7	219.0	121.2	102.5	0.553	0.468	77.9	41.4	23.9	9.1	14.8
1200	0.333	12.3	219.0	124.5	100.0	0.569	0.457	79.2	40.3	25.6	8.4	17.2
1300	0.278	15.5	219.0	126.5	100.0	0.578	0.457	79.6	39.3	26.5	8.2	18.3
1400	0.222	19.6	220.0	133.4	94.0	0.605	0.427	78.8	38.5	28.9	7.1	21.8
1500	0.167	24.4	220.0	152.5	88.0	0.693	0.400	74.5	37.6	35.8	6.0	29.8
1580	0.122	27.6	220.0	157.7	78.0	0.717	0.355	67.0	37.0	34.4	4.7	29.7
1620	0.100	27.9	221.0	166.4	70.0	0.753	0.317	62.0	36.7	35.1	3.7	31.4
1660	0.078	29.2	221.0	173.2	62.5	0.784	0.283	54.5	36.3	33.5	2.9	30.6
1700	0.056	26.1	221.0	187.2	52.5	0.847	0.238	44.0	36.0	31.6	2.0	29.6
1740	0.033	19.9	222.5	195.5	36.0	0.879	0.162	31.0	35.7	23.9	0.9	23.0
1780	0.011	10.	223.0	202.8	25.0	0.909	0.112	14.0	35.4	10.3	0.4	9.9
1800	0.0	....	224.0	208.0	14.0	0.961	0.062	....	35.3	....	....	....

derived from the polyphase curve will naturally be lower than in Table I, which appears to be the case in all the tests made.

The data in Table III indicate that the two motors have their

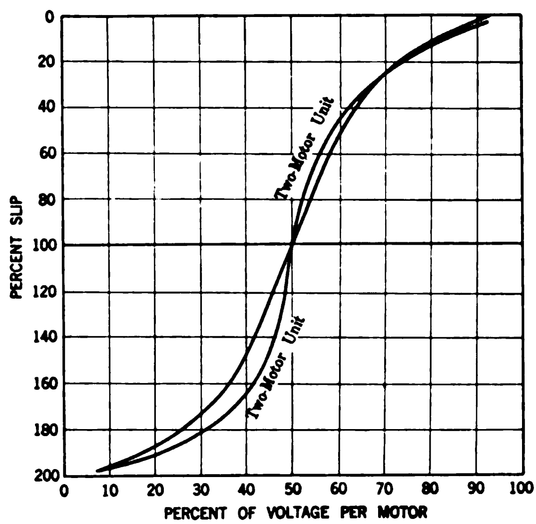


FIG. 24

primary voltages very nearly in phase at all times. The sum of the two motor voltages is never much greater than that of the line.

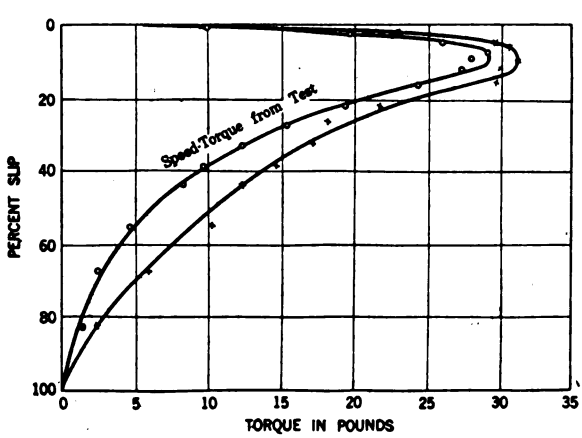


FIG. 25

In Fig. 25 is shown the calculated and tést speed-torque results corresponding to Table III. The test result shows lower torques at the low speeds than can be derived from the voltage percent-

TABLE IV.

Speed		Torque corrected to 220 volts	Volts			Ratic of volts		Polyphase torque at 220 volts		Polyphase torque at reduced voltage		Resultant torque
r. p. m.	Slip		Line	No. 1 motor	No. 2 motor	No. 1 motor	No. 2 motor	Forward	Back	Forward	Back	
340	0.811	1.71	219.0	114.3	108.0	0.521	0.493	79.6	76.1	21.6	18.5	3.1
480	0.734	4.93	219.0	117.8	105.0	0.538	0.480	79.7	75.0	23.0	17.3	5.7
640	0.645	7.85	219.0	122.1	102.0	0.552	0.470	79.1	73.5	24.1	16.2	7.9
810	0.555	11.2	219.5	126.4	98.0	0.576	0.446	77.8	72.0	25.8	14.3	11.5
1010	0.439	15.25	219.5	134.2	93.0	0.612	0.424	74.1	70.1	27.8	12.6	15.2
1220	0.322	20.5	220.0	146.3	83.0	0.664	0.377	67.5	68.5	29.8	9.7	20.1
1300	0.278	22.2	220.0	153.3	79.0	0.697	0.359	63.1	67.8	30.8	8.7	22.1
1410	0.217	23.8	220.0	164.5	70.0	0.748	0.318	55.5	66.9	31.1	6.8	24.3
1500	0.167	23.1	220.0	174.0	61.0	0.791	0.277	48.0	66.3	30.5	5.1	25.4
1600	0.111	20.1	220.5	187.0	47.0	0.848	0.213	36.5	65.5	26.3	3.0	23.3
1700	0.050	12.6	221.0	199.2	30.0	0.90	0.136	31.0	64.6	17.0	1.2	15.8
1750	0.028	6.0	221.0	204.4	24.0	0.925	0.109	12.0	64.3	10.3	0.8	9.5
1780	0.011	3.2	221.0	206.1	17.0	0.933	0.076	6.0	64.0	5.2	0.4	4.8

ages applied to the polyphase torques. Part of this difference may be due to temperature conditions.

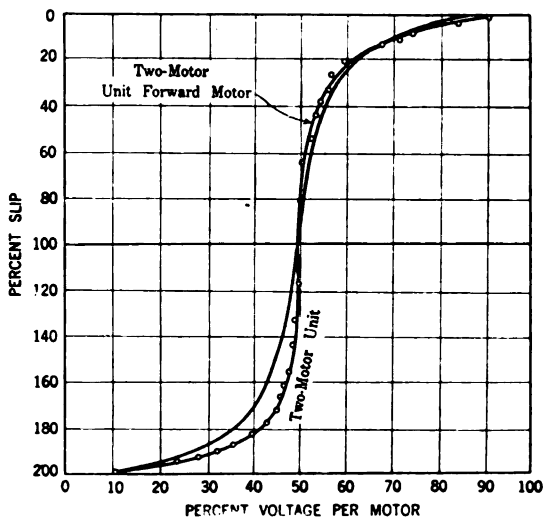


FIG. 26

In Table IV is shown the corresponding data for two motors with resistance in the secondary. Under this condition the various tests made were more consistent with each other and

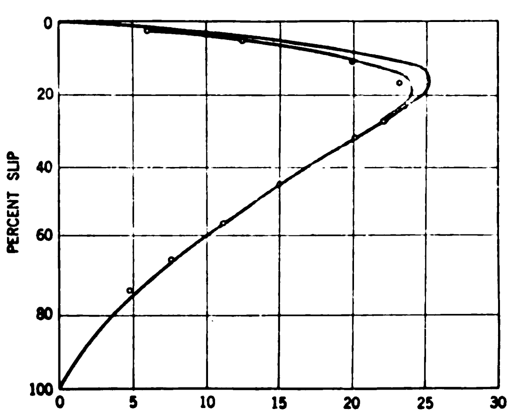


FIG. 27

the writer has more confidence in the data than in the case of Table III.

In Fig. 26 is shown the percentages of line voltage on each of

the two motors, compared with those in Table II. These show the same differences as in Fig. 24, where there was no external resistance.

In Fig. 27 is shown the speed-torque curve for both calculation and test, as taken from Table IV. Here the discrepancies are much smaller than in Fig. 25.

are

CONCLUSION

While the data is not as exact as the writer would desire, yet he feels that the general results obtained from the various tests have indicated that the method of analysis followed in this paper is along proper lines and that this conception of the action of the single-phase induction motor is of considerable assistance in obtaining a proper understanding of the machine. As stated before, the primary purpose of this paper is not to develop a method of calculation, but is simply to illustrate some of the characteristics of the single-phase motor. It is hoped that this will bring out more clearly the very intimate relation between the polyphase and single-phase induction motors in their operating characteristics.

PROCEEDINGS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS

Vol. XXXVII Number 5

MAY, 1918

A. I. E. E. Annual Meeting
Edison Medal Presentation
See Page 137, Sec. I.

ANNUAL CONVENTION

AT

ATLANTIC CITY, N. J.

June 26-28, 1918

See Program in This Issue

PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXVII
Number 5

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GEORGE R. METCALFE, Editor.

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVII **MAY, 1918** **Number 5**

ANNUAL MEETING AND EDISON MEDAL PRESENTATION

The annual business meeting of the A. I. E. E. will be held in the Auditorium of the Engineering Societies Building, on Friday, May 17th, at 8:30 p.m. The Board of Directors will present its report for the fiscal year ending April 30, 1918, which will contain a detailed statement of the Finances of the Institute and a summary of the work of the standing and special committees during the year. The Committee of Tellers will present its report on the election of officers for the coming administrative year.

The ceremony of presentation of the Edison Medal will follow immediately after the business of the annual meeting.

PRESENTATION OF EDISON MEDAL

The 8th Edison Medal has been awarded to Colonel John Joseph Carty for his work in the science and art of telephone engineering and the medal will be presented to Colonel Carty at the annual meeting. President E. W. Rice, Jr. will preside and the program will be as follows:

Address by A. E. Kennelly outlining the origin and purpose of the Edison Medal.

Address by Michael I. Pupin giving history of Colonel Carty's work in regard to telephone engineering.

Presentation of medal to Colonel Carty by President E. W. Rice, Jr.

Acceptance of the medal by Col. Carty.

Ladies are cordially invited to attend this meeting.

ANNUAL CONVENTION, JUNE 26-28, 1918

As previously announced the Annual Convention of the A. I. E. E. will be held at the Marlborough-Blenheim Hotel, Atlantic City, N. J., June 26-28, 1918.

President Rice has announced the following convention committee: J. Franklin Stevens, Chairman, Philadelphia, Pa.; N. A. Carle, Newark, N. J.; Walter A. Hall, West Lynn, Mass.; Charles Robbins, East Pittsburgh, Pa.; L. T. Robinson, Schenectady, N. Y.

This committee is making all arrangements for the convention with the exception of the technical sessions which are arranged by the Meetings and Papers Committee.

The program will be as follows:

Wednesday, June 26,

10:30 A.M.

Annual Address, by President E. W. Rice, Jr.

Introduction of the President-Elect.

Reports of Technical Committees

2:30 P.M.

Split-Conductor Cables—Balanced Protection, by Wm. H. Cole.

Overhead Transmission Cables, by E. B. Meyer.

The Application of Theory and Practise to the Design of Transmission Line Insulators, by G. I. Gilchrist.

8:30 P.M.

Informal Reception and Dance

Thursday, June 27,
10:30 A.M.

Lightning Arrester Spark Gaps, by C. T. Allcutt.
The Oxide Film Lightning Arrester, by C. P. Steinmetz.
The Oxide Film Lightning Arrester, by Crosby Field.
Design of Transpositions for Parallel Telephone and Power Circuits, by H. S. Osborne.

2:30 P.M.

Members and Section Delegates Conference.

8:30 P.M.

Fixation of Nitrogen, by E. Kilburn Scott.
America's Power Supply, by C. P. Steinmetz.

Friday, June 28,
10:30 A.M.

Pre-Charged Condensers in Series and in Parallel, by V. Karapetoff.
Method of Symmetrical Coordinates Applied to the Solution of Polyphase Networks, by C. L. Fortescue.
Sustained Short-Circuit Phenomena, and Flux Distribution of Salient Pole Alternators, by N. S. Diamant.

2:30 P.M.

Protection from Flashing in D-C. Apparatus, by J. J. Linebaugh and J. L. Burnham.
The Automatic Hydroelectric Plant, by J. M. Drabelle and L. B. Barnett.

Entertainment

The Convention Committee has arranged for an informal Reception and Dance on Wednesday evening, June 26th, at 8:30 p.m. and has also made arrangements whereby members who desire to play golf may obtain the privileges of the Atlantic City Country Club.

Hotel	Manager	Plan	Double rooms two persons		Single rooms one person	
			with bath	without bath	with bath	without bath
*Marlborough Blenheim.....	Josiah White & Sons Co.	American European	\$12—\$21 \$ 9—\$16	\$12 \$ 7	\$8—\$11 \$6—\$ 8	\$6—\$8 \$4—\$5
Brighton........		American	\$13—\$17	\$11—\$12	\$8—\$10	\$6
Chalfonte.......	The Leeds Company	American	\$12—\$20	\$10—\$12	\$9—\$15	\$6—\$9
Chelsea.........	J. B. Thompson & Co	American	\$12—\$16	\$10—\$12	\$8	\$6
Dennis.........	Walter J. Buzby	American	\$11—\$18	\$9—\$10	\$7—\$11	\$5—\$6
Haddon Hall....	Leeds and Lippincott	American	\$11—\$16	\$9—\$14	\$7—\$10	\$5—\$8
Shelburne.......	Jacob Weikel	European	\$6	\$5	\$4	\$3
St. Charles......	Newlin Haines Co.	American	\$10—\$13	\$8—\$9		\$5
Strand..........		American	\$12	\$10	\$7	\$6
Traymore.......	J. W. Mott	American European	\$10—\$18 \$ 6—\$14		\$9—\$16 \$5—\$12	

*Institute headquarters.

The bathing at Atlantic City is so excellent and the other attractions are so numerous and varied that it has been deemed inadvisable to make any arrangements for entertainment other than those mentioned above.

Transportation

No special transportation rates are available and members should consult their local ticket agents regarding routes and rates. Parlor and sleeping car accommodations should be engaged in advance.

Hotel Reservations

Members should make their own reservations for hotel accommodations. As Atlantic City is generally crowded, members are advised to make reservations well in advance. The list given herewith contains the names, addresses and rates of several of the well known hotels in Atlantic City. The number of hotels is so large that lack of space prevents giving complete list.

FUTURE MEETINGS

Chicago—May 28, 1918. Speaker, Frank A. Vaughn. Subject: Regulation of Street Series Lamps. Joint meeting with Illuminating Engineering Society.

Cleveland—May 20, 1918. Speaker, E. W. P. Smith. Subject: Engineering Cooperation in Civic Affairs.

Denver—May 18, 1918. Speaker, R. C. Mann. Subject: Wireless and Heliograph Signaling on Land and Sea.

Philadelphia.—Engineers Club Speaker, J. S. Francis. Subject: Fundamental Plans.

San Francisco.—May 24, 1918. Boat trip.

Spokane.—May 17, 1918. Subject: Engineering Education. Annual meeting—election of officers.

St. Louis.—May 29, 1918. Speaker, D. W. Roper. Subject: Electrolysis.

Washington.—McKinley Manual School. Annual meeting— election of officers.

THE 339th INSTITUTE MEETING IN PITTSBURGH AND NEW YORK

The 339th meeting of the American Institute of Electrical Engineers was an intersection meeting held in the Chamber of Commerce, Pittsburgh April 10 and in the Institute headquarters, 33 West 39th St., New York April 12.

The Pittsburgh session presided over by Mr. F. E. Wynne had an attendance of about 190. At the New York session Vice President B. A. Behrend presided and called the meeting to order at 8.15 p.m. The same papers were presented at both meetings, as follows: *No-load Conditions of Single-Phase Induction Motors and Phase Converters*, by R. E. Hellmund and *A Physical Conception of the Operation of the Single-Phase Induction Motor*, by B. G. Lamme. At the New York meeting Mr. Lamme presented his paper while Mr. Hellmund's paper was presented by A. M. Dudley and the following men took part in the discussion: Prof. M. I. Pupin, E. F. W. Alexanderson, L. W. Clubb, J. Slepian, A. M. Gray, R. E. Hellmund, C. A. M. Weber, A. M. Dudley, C. F. Scott, Selby Haar, C. Fortescue and B. G. Lamme.

Directly preceding the technical session a buffet dinner was served in the Engineering Societies Building to about 140 members and guests at a charge of 85 cents per person. This innovation proved such a distinct success that it is hoped to hold many such affairs at future Institute meetings.

DIRECTORS' MEETING, NEW YORK APRIL 12, 1918

The regular monthly meeting of the Board of Directors of the Institute was held at Institute headquarters, New York, on Friday, April 12, 1918, at 3:30 p.m.

There were present: President E. W. Rice, Jr., Schenectady, N. Y.; Vice-Presidents B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y., Frederick Bedell, Ithaca, N. Y., A. S. McAllister, New York; Managers F. B. Jewett, Wm. A. Del Mar, New York, John B. Taylor, Schenectady, N. Y., Harold Pender, Philadelphia, Pa., N. A. Carle, Newark, N. J., Walter A. Hall, West Lynn, Mass., C. E. Skinner, Charles Robbins, Wilfred Sykes, Pittsburgh, Pa.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $13,257.20, was ratified.

Upon recommendation of the Finance Committee, the Board of Directors voted to subscribe $10,000. to the Third Liberty Loan.

Upon the recommendation of the Board of Examiners, the following action was taken upon pending applications: 42 students were ordered enrolled; 208 applicants were elected to the grade of Associate; 9 applicants were re-elected to the grade of Associate; 6 applicants were elected to the grade of Member; and 8 Associates were transferred to the grade of Member.

A considerable amount of other business was transacted by the Board, reference to which will be found in this and subsequent issues of the PROCEEDINGS.

WILLIAM D. WEAVER
In Appreciation of Services

At the meeting of the Board of Directors held April 12, 1918, the following communication was presented:

April 5, 1918.

The President and Board of Directors,
American Institute of
Electrical Engineers,
New York City.

Gentlemen:

The undersigned members and fellows respectfully submit to the President and the Board of Directors of the American Institute of Electrical Engineers a petition asking for the acceptance of a permanent record in the form of a bronze tablet, to be placed in the room of the Board of Directors, in honor of Lieutenant William Dixon Weaver, Volunteer Chief Engineer, United States Navy.

The signatories have selected this year since it is twenty years ago that Mr. Weaver, laying aside his work and private duties, re-entered, as volunteer chief engineer, the United States Navy, at a moment of the nation's need.

The contemporaries of Mr. Weaver need no explanation of the reason why the signatories desire to do him honor and why they deem the rooms of the Institute the proper place for such record. We have, however, to remember the younger generation.

He was born at Greensburg, Pennsylvania, August 30th, 1857. He graduated in 1880 from the United States Naval Academy at Annapolis, studying at the Sorbonne and in London. In 1883 he went on the first Greeley Relief Expedition. He founded the *American Electrician*, he was editor of the *Electrical World* from 1893 to 1912. He re-entered the United States Navy as volunteer chief engineer in 1898. In 1900 he was appointed by the United States Government as the official delegate to the International Electrical Congress at Paris, but, upon his suggestion, the appointment was transferred to Dr. Kennelly, who had taken a more active part in the Congress work. In 1904 he was treasurer and business manager of the International Electrical Congress at St. Louis. He was twice a director of the Institute, and from 1901 to 1906 chairman of its Library Committee. In 1915 he was selected by the Board of Directors as one of the Institute's representatives on the Naval Consulting Board, but he declined on account of his health.

The Engineering Societies Building owes its existence to the munificence of Mr. Carnegie. At the Institute Library Dinner in 1903, which Mr. Carnegie

attended as guest of honor, Dr. Billings, then perhaps the greatest authority of the world on library administration and organization, Mr. Theodore De Vinne, our greatest printer, and Mr. R. R. Bowker who had the leading part in introducing the card catalogue, were the principal speakers. In their remarks they referred to the desirability of proper quarters for the great collection of books gathered by the American Institute of Electrical Engineers. Mr. Weaver prepared, and submitted to Mr. Carnegie, a proposition under which Mr. Carnegie was to donate an amount for the purpose of "housing" the library. Mr. Weaver wished to make this library a great library of reference on electrical, physical, engineering, and technical subjects generally, having complete files of important publications, notably the proceedings of the French Academy (donated by C. O. Mailloux) and the proceedings of the Royal Society (donated by E. D. Adams). The Library is Mr. Weaver's silent monument. "But for his extreme ly retiring disposition he would long since have been clothed with the highest honors which it is within the power of the profession as a whole to bestow * * * * The career of Mr. Weaver is notable * * * * also by reason of many other highly important results attained in his characteristic manner, without widespread public knowledge of his work therefor, but always with the assurance on his part that no credit was withheld from all others assisting in the work." E. W., May 4, 1912.

The signatories recognize in him the highest type of an American, Engineer, Scholar, Journalist, and Patriot, and they desire to dedicate to this Institute, in recognition, always so modestly veiled by him, of his services in the promotion of the welfare of the Institute and the engineering profession; of his untiring assistance and aid to men he deemed able and promising; of the creation of a journalistic forum in which independent opinions could be voiced by all; in rendering those columns familiar to great English, French, and other European writers; in having been instrumental, jointly with others, in securing a permanent home for the engineering societies, and in building up the Institute's Library and rendering it serviceable to the membership; in organizing and carrying to a successful conclusion the work of the International Electrical Congress at St. Louis and the Commission on Resuscitation from Electric Shock.

We conclude this brief memoir by citing the words of our Honorary Secretary, Mr. Ralph W. Pope:

"The most prominent feature, and which is a matter of record, is his building up of our great engineering library, which was practically accomplished by his exertions, guided by a most remarkable knowledge of engineering literature and his devotion to the highest ideals in the ever-growing field of electrical science."

Comfort A. Adams,
Edward D. Adams,
Bernard A. Behrend,
Louis Bell,
Andre Blondel,
Edward Caldwell,
John J. Carty,
Gano Dunn,
Thomas A. Edison,
William L. Emmet,
Carl Hering,
F. L. Hutchinson,
Arthur E. Kennelly,
C. O. Mailloux,
Addams S. McAllister,
Ralph D. Mershon,
William Onken, Jr.,
Michael I. Pupin,
Samuel Reber,
Harris J. Ryan,
Charles P. Steinmetz,
Nikola Tesla.

In response to this petition the Board of Directors unanimously adopted the following resolution:

Whereas a group of members of the Institute has presented a petition to this Board offering to donate to the Institute a bronze tablet for the

purpose of recording appreciation of the services rendered to the Institute and the electrical engineering profession by Mr. William D. Weaver and

WHEREAS Mr. Weaver has been an active member of the Institute for over thirty years and has ably served the Institute in various capacities including several years as Chairman of the Library Committee and six years as a member of the Board of Directors, be it

RESOLVED that the American Institute of Electrical Engineers hereby accepts the offer referred to above, and that the President be authorized to appoint a committee of three to confer with representatives of the petitioners; this committee to have power to complete the arrangements to carry out the intent of this resolution.

ENGINEERING SCHOOL REGISTRATION MUST BE MAINTAINED

In furtherance of the movement already instituted by the various engineering societies and colleges which resulted in a clause being added by the Provost Marshal General to Section 151 of the Selective Draft Regulations placing a certain proportion of engineering students in Class V (See PROCEEDINGS January 1918, "Status of Engineering Students Under the Selective Service Law") the Institute again urges the earnest and continued cooperation of all.

If we are to provide an adequate supply of engineers with thorough technical training to meet the ever increasing service demands, every effort must be made to not only keep the registration in our technical and scientific schools up to its usual standard number but to increase that number far beyond its normal rate of increase. We must look out not only for the present war needs, and the engineer regiments are said today to compose 6 per cent of an army's strength, but for that greater demand which will come at the conclusion of peace and the opening of a period of reconstruction of greater activity and opportunity than anything the world has ever known.

In England and France the technical schools are today practically empty and in our own the number of men has already fallen off between 25 and 35 per cent. As the average age of graduates is 23 years they are practically all not only subject to draft but they have shown an intense desire to enter the country's service. This desire largely extends to the undergraduates and it is these men who must have impressed upon them that in remaining and completing their education they will be just as patriotic and just as useful to their country as the men who join the army or navy. Every American youth not of military age and in any way qualified should feel it his duty to enroll in one of our technical schools and parents should make every sacrifice to keep their sons at school.

Another important phase of the situation is the corresponding shortage of instructors due to the constantly recurring demand for highly trained experts and specialists in the government organization. The withdrawal of these men from their usual pursuits must also be given the most careful attention and forethought.

At a meeting of the college presidents, deans and professors called by the Chief Signal Officer to meet at the Bureau of Standards in Washington, Dec. 29 last, to consider ways and means to increase the supply of technically trained men for signal service, the shortage of students and teachers developed, and out of the discussion came the appointment of a committee (Dean F. L. Bishop, Pittsburgh University; Professor A. E. Kennelly, Massachusetts Institute of Technology; Professor C. R. Mann, Carnegie Foundation, and Dean M. E. Cooley, University of Michigan) to draft resolutions to the President and Secretary of War; the President to be asked to send a message to the youth of the country to attend school and the Secretary of War to prevent depletion of teaching staffs.

The President was immediately responsive and at the meeting of the Department of Superintendence in Atlantic City on February 25, 1918 being unable to attend in person sent the following letter:

The White House
Washington

18 January, 1918.

My dear Dean Cooley:

I understand that there is to be a meeting of the department superintendents of the American Educational Association in Atlantic City on the twenty-fifth of next month. I would like very much to be present in person at that meeting, but since I cannot be, may I not ask you to express to the gentlemen assembled there my very great concern that none of the educational processes of the country should be interrupted any more than is absolutely unavoidable during the war.

My attention has lately been called in particular to the falling off in the number of engineering students and this has given me a good deal of concern, because it is not only immediately necessary that as many students as possible should prepare themselves for engineering duties in the Army and Navy, but it is also of the first consequence to the country that there should be an adequate supply of engineers for the period of reconstruction which must follow the war.

Not only has technical training become of enormous importance in military operations, but the role of the engineer has become more and more important in every process of our industrial life, and I hope that influences may go out from the meeting in Atlantic City which will call the attention of parents throughout the country to the importance of making any sacrifice that it is possible to make to keep their sons in the schools even during these trying times.

Cordially and sincerely yours,
WOODROW WILSON.

OLIVER HEAVISIDE
Elected an Honorary Member

In accordance with the procedure prescribed in the Constitution of the Institute governing the election of Honorary Members, a group of ten members presented to the Board of Directors at its meeting held in December last, a proposal in writing that Oliver Heaviside, mathematician and physicist, and Fellow of the Royal Society, London, be elected an Honorary Member of the American Institute of Electrical Engineers.

This petition has been favorably considered by the Board of Directors and by the unanimous vote of all of the members of the Board Mr. Heaviside has been formally elected to Honorary Membership.

In conferring upon Mr. Heaviside this mark of appreciation of the eminent services rendered by him to the scientific world, the Board adopted the following resolution:

WHEREAS, Oliver Heaviside has rendered service of the highest value in the advancement of electrical science leading to practical results of far-reaching order, and notably in the development of electromagnetic theory; and

WHEREAS, The Constitution of the American Institute of Electrical Engineers provides that, by unanimous vote of all the members of the Board of Directors, Honorary Members may be chosen from among those who have rendered acknowledged eminent services to electrical engineering or to its allied sciences; it is

RESOLVED, that Oliver Heaviside, Fellow, Royal Society, London, England, be elected, in recognition of his contributions to electrical science and engineering, to Honorary Membership in the American Institute of Electrical Engineers.

ENGINEERING FOUNDATION
Annual Report for third year, ending February 28, 1918

During the year terminating at the date for the third annual meeting of Engineering Foundation, the Board completed its undertaking to sustain the National Research Council for one year from September 19, 1916, to September 20, 1917. Under date of September 20, 1917, Secretary Cary T. Hutchinson presented a report to the Board of this year's activities. Progress was made also in the investigation on gears by Professors Guido H. Marx and L. E. Cutter, and on the preparation for tests of spray concealment of ships by Mr. Howard P. Quick. Various untoward circumstances prevented completion of these two investigations within the year.

Assistance given in the organization of the National Research Council has been amply justified by the results. The Council is now well established in a 4-story building at 1023-16th Street, N. W., Washington, and has recently secured another similar building nearby in order to house its increasing force. The breadth, importance and volume of work done have steadily grown. Foreign offices have recently been established in London and Paris. Dr.

H. A. Bumstead is in charge of the former and Dr. William F. Durand of the latter. The total expenditure by Engineering Foundation for the National Research Council was $9,036.09, derived partly from income of the endowment fund and partly from special gifts from Ambrose Swasey and Edward D. Adams. In May, Walter M. Gilbert was appointed Assistant Secretary of Engineering Foundation, with headquarters in Washington, his services being contributed by the Carnegie Institution. He also became and has remained to date Assistant Secretary of the National Research Council. In September, resolutions were exchanged between the Engineering Foundation Board and the National Research Council, setting forth a policy of continuing, reciprocal relationship, and a conference committee, Chairman M. I. Pupin, Dr. Charles Warren Hunt and Gano Dunn, was appointed to inform National Research Council of the readiness of Engineering Foundation to work upon definite problems suggested by the Council. No problems have yet been suggested.

This achievement of the Engineering Foundation Board in establishing National Research Council and maintaining relationships with it, is believed to be the first successful attempt to put engineers and scientific men in close touch for the carrying out of a comprehensive program, involving both research and engineering.

In December, Secretary Cary T. Hutchinson resigned and Engineering Foundation joined with United Engineering Society and Engineering Council in engaging as Secretary Alfred D. Flinn, who began his duties January 1, 1918. February 26, the Executive Committee of National Research Council elected the Secretary of Engineering Foundation an Assistant Secretary of the Council, without salary.

The past year has been a notable one. The Engineering Foundation faces the new year better prepared than ever before to advance the profession of engineering and the good of mankind.

SUMMARY OF PROCEEDINGS OF UNITED ENGINEERING SOCIETY MEETINGS OF JANUARY AND FEBRUARY, 1918

January Meeting

There was presented the audit of the official accountants showing the U. E. S. books correct and finances in sound condition.

Officers and committees for 1918 were elected and appointed as follows: President, Charles F. Rand, 1st Vice-President, Calvert Townley; 2nd Vice-President, Robert M. Dixon; Secretary, Alfred D. Flinn; Treasurer, Joseph Struthers; Assistant Treasurer, Samuel Sheldon. Finance Committee: John Vipond Davies, Chairman; William L. Saunders, Robert M. Dixon, Calvert Townley.

By-law 78 was amended to read: "The Secretaries of the Founder Societies and of the United Engineering Society shall be a House Committee, of which the Secretary of the United Engineering Society shall be Chairman."

A special committee—Charles Warren Hunt, E. Gybbon Spilsbury, Benjamin B. Thayer and Lewis T. Robinson, was appointed to report on the advisability of rotation of Presidents of United Engineering Society among the four Founder Societies.

The name of the Library was officially fixed as "Engineering Societies Library."

Uncertainties as to the terms of members of the Engineering Foundation Board were determined in accordance with a recommendation of the Secretary.

February Meeting

Attendance lacked two of a quorum.

By resolution, the portrait of Ambrose Swasey given by him in response to a request of the President of United Engineering Society, was accepted, this portrait to be hung in the Engineering Societies Library.

An extensive addition to the book stacks of the Library was received from the Civil Engineers and installation on the 14th floor was reported as completed.

A. I. E. E. HONOR ROLL

Members of the American Institute of Electrical Engineers in Army and Navy service with the United States and her Allies.

This list supplements those published in the five preceding numbers of the PROCEEDINGS and includes only those members who are in the armed forces and who have responded to the War Service card sent to the membership on Sept. 15, 1917, or have otherwise communicated with Institute headquarters.

Members in Army and Navy service who have not been listed are requested to furnish the Institute with their proper military designation.

ALDWORTH, EDWARD L.
Camp Meade.
ANTHONISEN, R. P.
30th Engineers.
ARNOLD, C. N.
Lieutenant, U. S. N. R. F.
BADGER, C. K.
First Lieutenant, Signal R. C.
BISHOP, ALBERT B.
Signal Corps.
BOSSHART HARRY J.
37th Engineers.
BYLLESBY, H. M.
Major, Signal R. C.
BRILL, OSCAR C.
Captain, Signal R. C.
BROWN, J. T.
37th Engineers.
COGSWELL, FREDERICK R.
Lieutenant, 53rd Infantry.
COMSTOCK, C. W.
Second Lieutenant, Field Artillery, N. A.
COOVER, MERVIN S.
37th Engineers.
CROWELL, GEO. G.
Lieutenant, junior grade, U. S. N. R. F.
CROWLEY, J. A.
14th Casual Co., M. M. Regt., Signal Corps
DIXON, HARRY J.
U. S. N. R. F.
DONNOHUE, J. J.
First Lieutenant, Aviation Section, Signal R.C.
DOUD, WILLARD
Lieutenant, junior grade, U. S. N. R. F.
EKSTRAND, CHARLES
Lieutenant, junior grade, U. S. N. R. F.
FOULKROD, RAYMOND
Second Lieutenant, Engineer, R. C.
GUNBY, FRANK M.
Major, Quartermaster, R. C.
HOWK, CLARENCE L.
First Lieutenant, Signal R. C.
HUMPHREY, KENNETH B.
Signal Corps.
JONES, ROBERT A.
First Lieutenant, Signal R. C.
KINSLEY, CARL
Captain, Signal R. C.
KOLLOCK, G. J.
Lieutenant, 37th Engineers.
LIPSCOMB, W. H.
Second Lieutenant, Aviation Section, Signal R. C.
LOZIER, CHESTER A.
U. S. Navy.
*MICKLER, CYRIL F.
37th Engineers.
MOULTON, VICTOR C.
Sergeant, 3rd Depot Battalion, Signal Corps.
MULLERGREN, ARTHUR L.
First Lieutenant, Q. M. C., N. A.
NASH, JOHN F.
Officers Training Camp.
NEALL, N. J.
Major, Quartermasters Corps, Construction Division.
OBERGFELL, RALPH M.
Engineering Div., Signal Corps.
PHINNEY, R. M.
First Lieutenant, Signal Corps.
QUICK, RAY L.
U. S. N. R. F.
RITTER, JAMES B.
Ordnance Dept.
ROBERTS, G. R. W.
U. S. Army.
ROBERTS, THEODORE C.
Major, Engineer, R. C.
RUSSELL, EDWARD G.
Aviation Section, Signal Corps.
RYERSON, WILLIAM N.
Captain, Engineer, R. C.
SCHNAKE, EDW. W.
56th Engineers
SHALLCROSS, S. M.
U. S. Navy.
STOVEL, RUSSELL W.
Major, U. S. Army.
SULTZER, PAUL O.
42nd Engineers.
THOMSEN, CHRISTIAN A.
6th Engineers.
TURNER, C. A.
Lieutenant, junior grade, U. S. N. R. F.
WADSWORTH, GEORGE R.
Major, U. S. Army.
WAITT, ARTHUR M.
Major, Engineer, R. C.

*Died in Service.

WENTWORTH, HERBERT H.
Ensign, U. S. Navy.
WILDER, CLIFTON W.
First Lieutenant, Engineer, R. C.
WOOD, CHARLES P.
Captain, U. S. Army.
WYCKOFF, HOMER J.
37th Engineers.

SUMMARY OF MEN IN SERVICE

U. S. Army:
Brigadier Generals 2; Colonels 6; Lieutenant Colonels 4; Majors 58; Captains 141; First Lieutenants 161; Second Lieutenants 97; Sergeants 13; Corporals 7; enlisted men 116; miscellaneous 28. Total 633.

U. S. Navy:
Lieutenant Commanders 9; Lieutenants 21; Lieutenants, junior grade, 74; Ensigns 15; enlisted men 13; miscellaneous 25. Total 157.

British and French Armies 10.
Grand Total 800

ENGINEERING COUNCIL ACTS UPON INDUSTRIAL EFFICIENCY

At its meeting of April 18 Engineering Council appointed a special committee on Industrial Affairs as mentioned elsewhere in this issue. Owing to the rapidity with which the Army and Naval Appropriation bills are being considered by Congress and the fact that these bills contain proposals opposed to well-tried industrial methods for improving efficiency and increasing production in manufacturing plants, the committee without delay drafted a resolution which was adopted by special action of Engineering Council. This resolution is as follows:

WHEREAS, the winning of the War imperatively demands highest efficiency and maximum production in every branch of industry, and

WHEREAS, we are informed that Congress has under consideration in the Naval and Army appropriation bills proposals to prohibit, diminish and condemn the payment to public employees or to employees of private establishments under Government control any cash reward, premium or bonus for superior service, and

WHEREAS, these methods if applied with due regard to wages, surroundings, health and safety of the employees, will increase efficiency and production, help win the War and preserve our institutions, be it, therefore

RESOLVED, that in the opinion of ENGINEERING COUNCIL, representing American Society of Civil Engineers, American Institute of Mining Engineers, American Society of Mechanical Engineers, and American Institute of Electrical Engineers, together having 33,000 members, it is vital to the winning of the War that no legislation nor other measure should be adopted which may interfere with highest efficiency and maximum production, but that on the contrary every proper means should be taken to increase efficiency and production.

This resolution was telegraphed to the Senate Committee on Naval Affairs and to Mr. Charles M. Schwab, as manager of the Emergency Fleet Corporation. It has also been sent to the Senate Committee on Military Affairs and to a number of engineers in the home states of the senators on these two committees with a request to these engineers that they communicate at once with their senators.

The objectionable clause in the Appropriation Bills is as follows:

"That no part of the appropriations made in this Act shall be available for the salary or pay of any officer, manager, superintendent, foremen, or other person having charge of the work of any employee of the United States Government while making or causing to be made with a stop-watch or other time-measuring device a time study of any job of any employee between the starting and completion thereof, of or the movements of any such employee while engaged upon such work; nor shall any part of the appropriations made in this Act be available to pay any premiums or bonus or cash reward to any employee in addition to his regular wages, except for suggestions resulting in improvements or economy in the operation of any Government plant."

Engineers, especially those engaged in industrial operations, will readily appreciate the serious effect which legislation of this character if passed would have upon private plants engaged largely or exclusively upon war work under the appropriations carried in these bills. It is most important that such measures should not be enacted.

A careful reading of the third pre-

amble of the resolution adopted by Engineering Council will show that the Council and its committee fully realize that the best interests of the workmen must be conserved and its action has no ulterior purpose to the contrary. The earnest desire of Engineering Council is patriotically to promote in every way the largest production and best efficiency of the country's industrial establishments.

Upon the subject matter of the resolutions presented on April 18 by Mr. F. P. Fish, Chairman of the National Industrial Conference Board, the special committee is now concentrating its attention and making a careful investigation. The resolutions are as follows:

WHEREAS, it is daily becoming more apparent that the winning of the war demands the highest efficiency in every kind of production, and

WHEREAS, many causes and circumstances have unfortunately operated to obstruct, diminish and even interrupt necessary war production, and there is much information and experience to justify the belief not only that we are in many instances securing less production per unit of time and person than heretofore, but that the country is continuously confronted with proposals to lessen the hours of production without first determining the wisdom of such action, and

WHEREAS, it seems that manufacturers are not fully alive to the necessity of not only providing the best and most systematic service instruction to new labor but should constantly be endeavoring by every practical means to improve the efficiency of the older force, the plant and themselves, and

WHEREAS, it appears that Congress has under consideration in the Naval and Army Appropriation bills proposals to prohibit, diminish and condemn the payments to public employes of private establishments under Government control any cash reward, premium, or bonus for superior service and to forbid time studies, and

WHEREAS, it appears that the members of the great Engineering Societies of the United States are peculiarly qualified by virtue of their knowledge and experience to express an opinion upon the present efficiency of our production and the most practical means of increasing the productive capacity of both management and men and to call to public attention questionable proposals threatening our efficiency as a nation and therefore our capacity to perform our full duty in this great struggle.

THEREFORE, BE IT RESOLVED that the National Industrial Conference Board respectfully requests the Engineering Societies of the United States to investigate and to publicly express themselves as to whether or not we are losing or gaining in industrial efficiency, and to state what causes, if any, in their opinion are influencing the condition, and in what manner broadly they believe our industrial efficiency can be further stimulated.

ENGINEERING COUNCIL'S GROWING ACTIVITIES

At the regular bi-monthly meeting of Engineering Council, April 18, many matters of common concern to engineers as well as some of public welfare, in which the Profession is interested, were acted upon. There was a large attendance and representatives from several other bodies appeared before the Council. The procedure for the admission of additional societies to membership in Engineering Council was perfected and several societies were nominated; important new committees were created, and statements of work done were received from committees previously appointed.

American Engineering Service has continued busily engaged with its staff responding to requests from the War, Navy and other departments of the Government for men for special services along technical lines. Chairman George J. Foran, of this Committee, reported that large numbers of names had been supplied through the cooperation of leading engineering and chemical societies. Special assistance is being given to the Ordnance Department in securing officers to expedite production; to the Navigation Bureau in finding men for the submarine service; to the Signal Corps in procuring special employees for aviation work, and to the Tank Corps in enlisting non-commissioned officers and mechanics. In connection with the last item the Military Engineering Committee of New York has supplied engineering specialists to interview candidates in the rooms of the American Society of Mechanical Engineers and the American Society of Civil Engineers, in the Engineering Societies Building, lent for the purpose. General arrangements for these interviews were made by Captain R. C.

Stevens of the Army Tank Corps through the offices of Engineering Council.

The War Committee of Technical Societies, of which D. W. Brunton is Chairman, has official connections with the War Department as well as with the Naval Consulting Board. It continues its function of culling the large numbers of new inventions and other suggestions constantly being received, selecting those which are worthy of investigation or development by the Navy or War or other departments. Manifestly, details of this Committee's work being of a confidential nature cannot be published.

On the recommendation of the Public Affairs Committee, Charles Whiting Baker, Chairman, a resolution was passed urging authorities of engineering schools of the country to direct all their resources to the winning of the war, in such ways as relieving from routine duties, so far as practicable, teachers engaged in work for the Government or upon other war work and allowing such teachers the assistance of under-graduate students; by crediting such students for this work, if it can properly be done, by relieving them of prescribed work in their courses, of less importance; by offering shops and laboratories for the solution of war problems, and by training under-graduates in the fundamentals of engineering even at the sacrifice of some specialization on subjects not connected with the war. The Secretary was directed to send copies of this resolution to the technical colleges.

Prof. L. P. Breckinridge, Chairman of the Fuel Conservation Committee, reported that matters of importance had been considered for the Fuel Administration and for the Bureau of Mines.

In order to follow up the good work in connection with waterpower legislation, begun by Engineering Council and to be prepared for effective action upon other questions arising in the broad field of utilization and conservation of water for municipal supply, power development, irrigation, sewage disposal and navigation, a new committee was created to be known as the Water Conservation Committee.

Matters concerning the welfare of engineers in the War Service of the Government, have received hardly more than accidental attention from the engineering societies and in some instances none at all, because of the lack of a suitable organization to deal with them. To meet these needs in a broad way, Engineering Council authorized the appointing of a Military Aid Committee to deal with activities ranging from supplying the needs of some engineering unit in training camp or in combatant service to assisting the Government authorities in recruiting special engineering units or utilizing military engineering units on public works after the war.

The oft recurring question of licensing or registering engineers under state laws, was raised by one of the representatives on the Council and by a reference from the American Society of Civil Engineers. This matter was referred to the Public Affairs Committee for study and the organizing of a special sub-committee to deal with the subject actively.

Chairman J. Parke Channing, of Engineering Council, announced that the following well-known engineers had accepted appointment on the Patents Committee, created by the Council at its February meeting: Charles A. Terry, Chairman, C. A. P. Turner, Corydon T. Purdy, J. Parke Channing, Horace V. Winchell, Edwin J. Prindle, D. S. Jacobus, Frank N. Waterman. This committee will investigate reforms in the United States Patent System and in the use of experts in litigation wherein the validity of patents or other technical matters are involved, co-operating with similar committees of the National Research Council and technical societies.

By invitation, President F. P. Fish of the National Industrial Conference

Board presented personally to Engineering Council, resolution adopted by the Board at meetings being held in New York City. These resolutions requested Engineering Council, as the representative of the great engineering societies of the United States, to investigate and publicly express itself as to whether or not the Nation is gaining or losing in industrial efficiency and what causes, if any, are influencing the condition, and in what manner, broadly, it is believed, industrial efficiency can be further stimulated. These resolutions also urged opposition to proposals under consideration in Congress in connection with appropriation bills to prohibit, diminish, and condemn the payments to public employees, or employees of private establishments under Government control, of any cash reward, premium or bonus for superior services. Mr. Fish was accompanied by Mr. James A. Emery of the War Labor Board, who presented strong arguments in support of the resolutions. By vote of Engineering Council, the Chairman appointed as a special committee to give this matter immediate attention; Prof. George F. Swain, Chairman, E. W. Rice, Jr., Chas. T. Main, Alexander C. Humphreys and Benjamin B. Thayer all of whom are men well informed upon large industrial affairs.

At the request of the War Committee of Technical Societies, an officer who had had extensive experience on the Western Front, explained to the Council the importance of having a suitable proportion of engineers, superintendents and foremen, who had had practical experience in construction work, properly distributed among the fighting troops in addition to those in the engineering and labor regiments.

The relationship of Engineering Council to local societies and to the local sections or associations of the National Societies, received extensive consideration and will come up for action at a later meeting of the council.

COMMITTEE ON SAFETY CODES

Amendment to By-laws.

At a meeting of the Board of Directors held April 12 amendments to the by-laws were adopted, changing the name of the Code Committee to "Committee on Safety Codes", and inserting the word "accidents" after the word "fire", so that Section 29 of the by-laws now reads as follows:

Sec. 29. The Committee on Safety Codes shall consider and investigate all matters relating to the formulation of rules for the protection of persons and property against fire, accidents, and other hazards in connection with electrical installations and equipments, and shall confer with similar committees of other bodies regarding the same. The committee shall make reports and recommendations to the Board of Directors for action thereon.

COMFORTS FOR THE ENGINEER REGIMENTS

The New York Section of the Woman's Auxiliary to the American Institute of Mining Engineers has been granted the use of the ladies' reception room on the first floor of the Engineering Societies Building for a war relief work room. It will be open daily from ten until five, except Saturday, when it will close at one.

Any of the ladies in the families of the members of the A. I. E. E. who wish to help in the work of preparing comforts for the Engineer Regiments will be very welcome at any time they find it convenient to come in.

FOURTH SERIES OFFICERS' TRAINING SCHOOLS

1. A fourth series of officers' training schools will be held beginning May 15, 1918. The only civilians eligible for admission to these schools are those who received military instruction at recognized educational institutions where an officer of the Army was detailed. Those who have not received this instruction are ineligible and application can not be

considered. Those who have received such instruction should submit applications direct to the Professor of Military Science and Tactics at the institution attended.

Three classes of citizens will be selected to attend these schools:

a. Graduates of the course prescribed for the Reserve Officers' Training Corps.

b. Members of the advanced course, Reserve Officers' Training Corps, who have completed one year's course of same, and also have completed not less than 300 hours of military instruction and training since January 1, 1917.

c. Graduates other than those specified above who are between the ages of 20 years 9 months and 32 years, and who have had at least one year of military instruction at an educational institution under the supervision of an officer of the Army while attending same.

2. Men under class C should apply in writing to the Professor of Military Science and Tactics of the institution from which they graduated, including the following information:

a. Full name.
b. Years attending the institution.
c. Legal residence.
d. Date and place of birth.
e. Citizenship.
f. Weight and height.
g. A detailed statement of all military service and training.
h. A detailed statement of all experience and opportunities for leadership.
i. That it is thoroughly understood and agreed that if applicant is selected to attend a training school, he will enlist for the period of the war; that if not found eligible to be listed, will serve in the ranks, and if listed as eligible, will remain on duty as an enlisted man until such time as he may be appointed second lieutenant.
j. There should be submitted with application a detailed report of physical condition made by a well-known doctor or surgeon; the scope of this physical examination to be equivalent to that prescribed in regulations for a commission in the Officers' Reserve Corps, the requirements of which can be obtained from the officer on recruiting duty in the locality in which the applicant resides.
k. At the time application is mailed, applicant should have three letters written by three well-known and reputable citizens, none of whom should be related to him, testifying to his character and standing in the community in which he lives, and giving their opinion as to the fitness of the applicant for a commission as an officer. These letters should be mailed separately and directly by the writers to the authorities of the educational institution, and should not be inclosed with application.

3. All applications must be in the hands of the officials of the educational institutions not later than May 1. No applications will be received or considered by the War Department.

4. The selection of the quota assigned to each educational institution will be made only by the authorities of the institution themselves and not by the War Department. All inquiries regarding the selection of candidates should be made to the authorities of the institution and not to the War Department.

GOVERNMENT SERVICE

Submarine Service: The Institute has been requested by the Bureau of Navigation, Navy Department, to make nominations, in groups of twenty-five each, of specially qualified electrical engineers, for submarine duty with the United States Naval Reserve Force. The qualifications specified are as follows:

(1) A desire to serve in submarines.

(2) A degree as mechanical engineer, electrical engineer, or mining engineer, conferred by a college of recognized technical standing.

(3) At least two and one-half years of practical engineering subsequent to graduation (exclusive of time spent as sales agent).

(4) The candidate must not be over thirty-five years of age.

(5) Physically strong and sound in health.

The names of those nominated by the Institute will be forwarded to the Bureau of Navigation, and the Bureau will submit them to the Commander, Submarine Force, for further selection of an eligibility list, which will be drawn upon from time to time to meet the requirements of the new submarine classes. The candidates who are selected will be commissioned as Ensigns in the Naval Reserve Force and will be sent to the Naval Academy for an intensive training course. Those who complete this course successfully will be

sent to the submarine school for the special technical course preliminary to becoming part of the active submarine officer complement of the Navy.

The courses of instruction at the submarine school require specialization in electricity, diesel engines, torpedoes and submarine operation.

The Provost-Marshall General of the Army states that any person subject to the Selective Draft Law may be released therefrom to accept a commission in the U. S. Naval Reserve Force.

Members of the Institute or other persons possessing the qualifications specified, who desire to have their names submitted to the Bureau of Navigation as being available for this service, are requested to notify the Secretary of the Institute giving sufficient information to show that they meet the requirements.

Instructors, Officers' Training Shool: The Government proposes to establish immediately at Camp Humphreys, Va., a training school for replacement troops for the Engineer Corps. These men will be given intensive training to fit them for the special service required in connection with the various engineer units in the service.

As this school will have an ultimate capacity of approximately 30,000 men, many instructors will be required, and an appeal is made to qualified men above draft age who are willing to volunteer their services and enlist in the Engineer Corps as instructors in this school. These men must be qualified to give instruction to machinists, blacksmiths, wheelwrights, carpenters, concrete foremen, electricians, dynamo experts, miners, painters, riggers, sheet metal workers, foundrymen, automobile and motor truck gas engine men, draftsmen, photographers and general foremen of construction, and therefore a thorough knowledge of these lines is essential.

The applicant will be required to furnish proper credentials showing his knowledge of any one of the above lines. Full particulars and application blanks will be furnished by applying to Captain Louis T. Grant, E. R. C., Secretary, Engineer Training Schools, Camp Humphreys, Va.

Bureau of Mines: Important chemical and other technical engineering work necessary for the prosecution of the war is being carried on by the Bureau of Mines Experiment Station, at Washington, D. C. The services of trained men of the following classifications are urgently needed: Bacteriologists; Biologists; Chemists, Inorganic; Chemists, Organic; Chemists, Physical; Chemists, Electro-; Chemical Engineers; Draftsmen; Electrical Engineers; Instrument makers; Laboratory Assistants; Laborers; Machinists; Physiologists; Plumbers; Steamfitters; Stenographers; Skilled labor of various kinds.

Those whose training fits them for any of these occupations, should send to the Bureau of Mines, American University Experiment Station, Washington, D.C., for blank forms. When properly executed and returned, these forms will be placed on file, and when a vacancy occurs will be considered and applicants notified if services are desired.

Registrants in the draft, not yet ordered to camp, may be immediately inducted into the service for work here.

Those *not* in the draft, who wish to serve their country in the present crisis, can enlist, or serve as civilians.

The Coast Artillery Corps will require many additional officers within the next few months and offers an exceptional opportunity for men of technical education to work for commissions.

Only graduates of the training camp at Fort Monroe, Virginia are appointed officers. A three months' course is given, starting early in January, April, July and October. It is expected to continue this throughout the war. Candidates are selected from among enlisted men of the coast artillery, by boards of officers convened in all commands. To become eligible, therefore, it is necessary to enter the service as an enlisted man. One not registered for draft may enlist at any recruiting

station. A registered man should write to the Chief of Coast Artillery, Washington, D. C., stating his qualifications. Authority for his induction into service will then be asked for; and, if this be granted, a letter will be furnished to the applicant directing his local board to place him in service and send him to a coast artillery post.

It should be clearly understood that no promise can be made to any applicant that he will be selected for the training camp if enlisted, or that he will be graduated if sent to the camp. This depends entirely upon the man himself. If unsuccessful, he will continue to serve as an enlisted man. If successful, he will be appointed second lieutenant and assigned to duty as such immediately upon completion of the training camp course. As the demand for officers is continual, it is unlikely that any man of suitable education and character will fail to secure promotion, though, as already stated, no promise can be made.

Engineering graduates are especially desired, but a technical education is not essential for all officers. A man who has completed a year or more of college work, including courses in plane trigonometry and the use of logarithms, has an excellent chance of winning appointment if he enters the service before the first of July.

Forest Service: The Forest Products Laboratory is in urgent need of engineers' services probably for the period of war. The work will be primarily of an experimental and research nature embracing principally investigations of the mechanical and physical properties of wood, practical problems of the pulp and paper industry, etc. Work in connection with proper kinds and use of wood in airplane construction, methods of artificially drying wood, strength of built-up veneers, etc. Openings are of two grades: Engineers, age 25 to 45, graduate civil or mechanical engineers or equivalent, 3 years practical experience in research and in testing materials, salary $1,860 to $3,000 a year, Assistant Engineers, age 20 to 40, graduate civil or mechanical engineers or seniors in such, or at least four years practical work in such branch of engineering, salary $1,200 to $1,800 a year. For circular giving complete information apply to O. M. Butler, Asst. Director, Forest Products Laboratory, U. S. Dept. Agriculture, Madison, Wisconsin.

J. WALDO SMITH RECEIVES JOHN FRITZ MEDAL

On the evening of April 17 at a meeting held in the auditorium of the Engineering Societies Building, New York, the John Fritz Medal was presented to J. Waldo Smith chief engineer of the New York Board of Water Supply, for his achievements in connection with the Catskill Aqueduct. Col. John J. Carty, Past-President of the American Institute of Electrical Engineers presided; addresses were delivered by Nelson P. Lewis and Hon. A. T. Clearwater. The presentation of the medal was made by Ambrose Swasey, Past-President of the Amer can Society of Mechanical Engineers.

NOTES ON ENGINEERING PROGRESS IN BRITAIN

By H. M. Hobart

Last September I went to London to represent the Standards Committee at a conference with the British Engineering Standards Committee. This constituted the third of a series of Anglo-American Conferences on Standards for Electrical Machinery. The first occasion was in February, 1915, when the Institute in response to the British Committee's invitation, sent as its delegates to a London Conference, Mr. C. E. Skinner and myself. The second conference was in the spring of 1916, when the British Committee accepted an invitation from the American Committee by sending to New York as its delegate, Mr. C. le Maistre, with whom many

Address delivered March 19, 1918 at Boston Section meeting.

of you have become well acquainted. At the time of le Maistre's departure from London in May, 1916, he was the Electrical Secretary of the Engineering Standards Committee, the General Secretary being Mr. Leslie Robertson. But in June, while le Maistre was in America, Mr. Leslie Robertson was appointed to accompany Kitchener to Russia and, as you know, the ship either struck a mine or was torpedoed and none survived. On le Maistre's return to England a few weeks after this occurrence, he was offered and accepted the position of General Secretary of the Engineering Standards Committee.

Mr. le Maistre has for many years, as Secretary of the International Electrotechnical Commission, taken a keen interest in standardization and is making a splendid success. Indeed, the British Engineering Standards Committee is far and away the biggest and most influential standardizing organization in the world.

Since I left London in December the Engineering Standards Committee has sustained a severe loss in the death in his 84th year, of its Chairman, Sir John Wolfe-Barry. Wolfe-Barry had been Chairman ever since the committee was formed. From a paper entitled "Standardization" which le Maistre read at our summer convention at Cleveland in June, 1916, I wish to read a brief extract:

"The initiation in 1901 of the British Engineering Standards Committee, the greatest private voluntary effort of the kind, is due to Sir John Wolfe-Barry whose name is a household word among British engineers. His commanding influence in the engineering world, and the deep respect in which he is held by the whole profession has probably been the greatest factor in bringing this organization to its present unassailable position. It had a small beginning, but has increased in scope and efficiency till today its influence is felt and its specifications acknowledged and worked to throughout practically the whole of the Empire."

It was the middle of last November, less than two months prior to Wolfe-Barry's death, that I accepted his invitation to attend a meeting of the Main Committee of the Engineering Standards Committee. I am not certain, but probably this was the last Standards meeting over which Wolfe-Barry presided.

In America a really self-respecting engineer begins to have conscientious scruples at the age of fifty, about taking upon the stage space that could be more ornamentally occupied by younger men, but of the twenty members who on that occasion sat around the table in the beautiful council room of the Institution of Civil Engineers, in Great George Street, Westminster, four were over seventy five years of age and at least eight must have been over sixty years old. During the hour occupied by the meeting of this Main Committee these men of advanced age and ripe experience and judgment handled expeditiously but with high efficiency and appropriate thoroughness, a wide varietv of important matters.

On the occasion of a welcoming luncheon to the Standards Committee's delegate, Wolfe-Barry made an address so full of sincere kindly feeling for America that I wished to share it with others over here. So le Maistre was good enough to have it printed and I will read a few lines:

Wolfe-Barry said:

"While on this subject of the community of interests of the two nations in the particular matter under discussion, I cannot help alluding to the difference which exists at the present moment in the political relationship of the two nations as compared with the position on the occasion of Mr. Hobart's previous visit.

It is a matter of profound satisfaction to all classes in this country that the two nations are now firmly united in a mission of Mercy, Liberation and Morality towards all the other nations of the world except only, of course, those controlled or influenced by the militarism and brutality of Germany.

We are now working in the closest alliance for the benefit of Democracy, by which I understand the interests of each different nation and of the individuals which form them.

Neither the United States nor Great

Britain have any designs of aggrandisement. They do not wish to add to their territory, or to oppress or control other nations, but to secure liberty for all to develop in their own lines. It is a matter of the most profound gratification that the two great Governments of the Anglo-Saxon race are now marching side by side in the great endeavor to forward the interests of humanity, having both of them the same ideals and aspirations to the world now so sorely afflicted by war and its attendant miseries."

The 1917 "James Forrest" lecture was delivered by Wolfe-Barry last May and was entitled "The Standardization of Engineering Materials and its Influence on the Prosperity of the Country." Wolfe-Barry summarizes his views on standardization as follows:

"The work being undertaken by the Standards Committee is of the utmost value—in the first instance to the buyer of electrical machinery in so far as it enables him to know what he can purchase and to be sure that he gets what he asks for in return for his money. It is of equal value to the manufacturer, as it simplifies his work in the competition with other nations and enables him to produce what is required by the purchasing public cheaply and expeditiously and to avoid mistakes.

The community of interests of buyer and seller is one of the main objects of Standardization, and there can be no doubt that the interests of both are really identical. This was the fundamental idea under which the work of the Engineering Standards Committee in this Country was founded some 17 or 18 years ago, and upon which it is still firmly based. The meeting of both interests in the drawing up of Rules and Specifications is not only of great value to both parties in the business, but is also to the important advantage of the country at large."

I could tell you a great deal more about the Standardizing Conferences which I attended, but I should prefer not to do so since it would not leave me any time to comment upon a few amongst the engineering matters to which my attention was drawn and which I felt were of considerable interest.

The progress of engineering in Britain has for long been characterized by extreme individuality. Without statistics at hand I cannot say how many firms are engaged in manufacturing electrical machinery but will content myself by saying that the industry has been split up to a very many times greater extent than in America. Moreover, the greater proportion of these little firms have aspired to manufacture many different kinds of things. A prospective customer received a large number of competitive tenders and it was not unusual for the order to go to some firm which through faulty estimates had tendered below cost. Prior to the war the electrical industry in Britain was at low ebb. Many firms found their salvation in substituting munitions and other war work for electrical machinery. In so far, however, as they continued to manufacture electrical machinery, this also was done under improved conditions due to the cutting off of German product and due to the sudden demands of the Admiralty and War Departments for large quantities of electrical apparatus.

The general convulsion has, however, brought about a serious spirit of investigation and the results are leading to a complete change of policy. Many new associations of manufacturers have sprung into existence and even in cases where actual consolidations may not have been effected or in contemplation, a policy of seeking to avoid destructive competition is very much in evidence. During the very darkest periods of the long struggle, Britons have never ceased to plan to meet "after the war" conditions. A very important Government Department presided over by a cabinet minister and known as the Ministry of Reconstruction has been formed. Under the auspices of this Ministry several able committees have been formed to investigate and report on timely propositions. One of the most important of these is the Coal Conservation Subcommittee. An interim report issued by this subcommittee in December is of intense interest to electrical engineers. The chairman of this subcommittee is Mr. Charles Merz of the well-known

consulting engineering firm of Merz and McLellan. The report calls attention to the enormous wastes associated with the present electricity supply situation in Great Britain. The public supply is obtained from some 600 undertakings. In the London area alone there are over 100 generating stations selling electricity to customers, in addition to nine traction stations each supplying one of nine different railways. I visited the two newest of these traction stations, which supply respectively the electricity for operating trains on the London & Northwestern and the London & Southwestern railway. Each of these railways has inaugurated its service of electric trains since the war and each owns and operates its own generating station. Each has a matter of some three times more installed capacity than would be ample for its present train service and neither can increase this train service materially before the conclusion of the war. The service was in both cases inaugurated while the conditions were still far less acute than they are at present, indeed at a time when it was only natural to expect an early conclusion of hostilities. Nevertheless, here we have two fine stations, each lavishly equipped with the most modern machinery for coal handling and up to date in all other respects, at a distance of only a very few miles from each other and in a district already provided with many other large, expensive, underloaded stations. But it is entirely consistent with the British traditions that each railway shall manufacture its own steam locomotives as well as all the rest of its own rolling stock. One British railway builds its own electric railway motors; and they are excellent, rugged motors. Indeed, this railway (the Lancashire and Yorkshire) has been more progressive in studying and employing electric traction than any railway in the whole world, and I do not forget any American railways when I make this statement. Its General Manager, Sir John Aspinall, has recently designed and installed a very interesting side-running third rail on the 1200-volt line running from Manchester to Bury. A few years ago he successfully operated an experimental section of his railway at 3500 volts direct current with an overhead conductor, and supplied his electricity from a single-commutator 3500-volt generator. Long ago Aspinall operated a regular service of 3-coach trains made up of two motor cars and a trailer, at a schedule speed of 30 miles per hour with one stop per mile. This required four 200-h. p. motors on each motor car, or 1600 h. p. for his three-car train.

Let us return to the report of the Subcommittee on Coal Conservation. The report recommends the division of Britain into sixteen districts. Each district shall be supplied from one or more generating stations. The loads on each station will be so great as to require the installation of generating sets of some 50,000 kw. each. These super-power plants will be placed at whatever locations represent the most efficient compromise as regards condensing water supply and coal supply. Electro-chemical industries and other suitable activities will be located near these stations and their load factor will be very high. Whenever the economic conditions obtain, by-products will be extracted from the coal before it is burned under the boilers, the by-product plant being combined with the power plant. In each district there will be *one* authority dealing with all the generation and *main* distribution. The entire project will probably come under a National Board of Electricity Commissioners "with power to fix maximum prices and a sliding scale of prices and dividends, and to control the terms upon which capital should be raised."

When all the factors involved in this project are taken into account, it becomes evident that electricity will be available in the neighborhood of these stations at a cost of an altogether different order of magnitude than could possibly be attained with the present conditions involving 600 stations in

various degrees of obsolescence and decrepitude.

The carrying out of this project would, according to the estimates in the report, reduce from its present value of 80 million tons down to 25 million tons, the annual coal consumption for power purposes (including railways) in the United Kingdom. This is on the assumption of the same amount of power developed under the new plan. But the power per employe is now only half of that in the United States. As a consequence, the earning power of the employe is limited. This must be at least doubled if Britain is to compete successfully in the World's markets. Thus it is reasonable to estimate that the coal consumption for power purposes will soon be 50 million tons per annum and that this will provide twice the power now obtained by burning 80 million tons of coal per annum. In the words of the report: "The present coal consumption would, if used economically, produce at least three times the present amount of power."

The report points out that "improvement in the commercial prosperity of a country—that is to say, the average purchasing power of the individual—depends on increasing the output per head." It states that while; "it is possible to increase the output per head by harder work on the part of each individual, there is far greater promise in increasing his output by giving him more machinery to multiply the effectiveness of his efforts." The report furthermore puts up the proposition that: "the best cure for low wages is more motive power," or, from the manufacturer's point of view: "the only offset against the increasing cost of labor is the more extensive use of motive power"

The Report of the Sub-committee has drawn forth an enormous volume of criticism. Much of this is based on the contention that the right conditions as regards cheap and plentiful coal and plentiful water are rarely found near one another in most parts of Britain. Others contend that the transmission and distribution costs associated with the electric scheme will be greater than the costs of conveying the coal by rail to stations located, as at present, near densely settled areas. Others display deep concern for vested interests and protest that in any case the change ought to be spread over a very long period.

But the prevalent temper of the British is comparable to a sort of Great Awakening and I venture to predict that something of this sort, or at any rate something thoroughly equivalent in bigness and boldness, will be pulled off. It must be remembered that any satisfactory reconstruction program must provide national work for the millions of men now in France. This has been a leading consideration in the decision arrived at last December to establish several great National Dockyards for the construction of merchant ships and naval vessels. The private shipyards were strongly opposed to this National enterprise. They contended that their inability to more rapidly increase their productive capacity for ships was in large part due to shortage of labor for building fabricating shops and ways and other structures, and for constructing the required machinery and equipment for putting these new shops in working order. And they believed that more could be done by them (in virtue of their experience) with the limited man-power available, than could possibly be done were this man-power diverted to constructing and equipping these great new National Dockyards. Probably a leading reason for the adoption of the National policy was that it would permit of an orderly continuance of shipbuilding and the employment of large numbers of men after the war and a freedom from the consequences of such industrial fluctuations in the demand for labor as might have occurred had private shipbuilding firms unduly extended their plants.

Practically all industries and supplies in Britain are "controlled" by more or less capable autocrats. Gasolene can

only be obtained by those employing their automobiles on war work, and even then the quantity is carefully stipulated. Many taxicabs in London have their roofs fitted with huge gas bags held in place by straps. These bags are filled with gas from the city mains and can run a few miles on one charge. When the gas is more than half consumed the bags present a very shapeless appearance, but after a fresh charge the outfit is quite ship-shape.

This change from liquid fuel to gas fuel is only one of many similar expedients. Shortage of carbide and consequently of acetylene has led to the wide substitution of arc welding in place of oxy-acetylene welding. Prior to the war, a large quantity of Russian oil was employed in transformers and switches, notwithstanding that it cost twice as much as American oil, because it was much less subject to sludging. But during the war the Russian oil could no longer be obtained and American oil was being employed, though with much reluctance because of the sludging troubles attending its use and there was general agreement to use the Russian oil again as soon as it could be obtained.

I was much impressed with the rapid progress in employing iron-clad switchgear built together as a complete machine as contrasted with the panel and cell systems used in America. Already three years ago this iron-clad gear was used widely on customers' premises and in substations, but there are beginning to be symptoms of its also competing with the American outfits for high-voltage work in generating stations.

It is impossible to do otherwise than admit and wonder at it, that, although the British have finally and very reluctantly taken down the sign "Business as Usual" which they took pride in displaying during the early stages of the war, there is an enormous amount of fine engineering progress being made in Britain even in these darkest of dark days.

PAST-SECTION MEETINGS

Baltimore.—January 18, 1918, Johns Hopkins University. Paper: "Metric Weights and Measures in Education, Engineering and Commerce" by Howard Richards, Jr. Attendance 15.

March 8, 1918. Johns Hopkins University. Illustrated address by Mr. S. W. Dudley on "Air Brakes." Attendance 28.

Boston.—March 19, 1918, Engineers' Club. Illustrated address by Mr. John B. Taylor on "Vibrations". Attendance 75.

April 9, 1918, Engineers' Club. Paper: "Electrical Business in Europe at the Present Time" by Stephen Q. Hayes. Attendance 50.

Chicago.—March 25, 1918, Western Society of Engineers Rooms. Address by Mr. Charles F. Burgess on "Some Possibilities in the Electrochemical Industries." Attendance 125.

Denver.—March 16, 1918, Denver Athletic Club. Address by Lieut. Harry W. Lait, of the 20th Canadian Battalion, First Canadian Division, on "Trench Warfare and His Personal Experiences in the War." Attendance 54.

Detroit-Ann Arbor.—March 15, 1916, Detroit. Paper: "Electric Equipment and Electric Drive for Battleships". Attendance 325.

Indianapolis - Lafayette.—April 2, 1918, Chamber of Commerce. Illustrated address by Mr. E. R. Shepard on "The Work of the Bureau of Standards with Special Reference to Electrolysis and its Mitigation." Attendance 35.

Milwaukee.—April 10, 1918, City Club. Paper: "Automatic Control Apparatus for Temperature Control in General, and also as Applied to the Refrigerating Industry" by Charles L. Fortier. Attendance 70.

Philadelphia.—April 8, 1918, Engineers' Club. Paper: "Inductive Interference of Alternating-Current Rail-

roads upon Communication Lines" by H. S. Warren. Attendance 215.

Pittsfield.—March 14, 1918, Hotel Wendell. Illustrated lecture by Mr. George A. Round on "War and Peace Problems of Automotive Engineers." Attendance 85.

April 1, 1918, Hotel Wendell. Annual Banquet. Adresses by President E. W. Rice, Jr., of the Institute, and Judge C. L. Hibbard and Mr. H. H. Ballard. Attendance 168.

Portland.—March 4, 1918, Multnomah Hotel. Paper: "The Building of Camp Lewis" by George Mason. Attendance 66.

April 2, 1918, Multnomah Hotel. Paper: "Changes in a Distribution System on Account of Range Load" by John B. Fisken. Attendance 46.

Rochester.—March 22, 1918. Paper: "The Design and Manufacture of Porcelain Insulators" by A. O. Austin. Attendance 40.

San Francisco.—March 20, 1918, Palace Hotel. Dinner in Honor of Prof. George F. Swain. Address by Professor Swain on "National Issues of To-day." Dr. Benjamin Ide Wheeler, and Messrs. P. M. Downing and Max Phelan also addressed the meeting. Joint meeting with local sections of other national engineering societies. Attendance 60.

Schenectady.—April 5, 1918, Edison Club Hall. Address by Lieut. Col. Nugent H. Slaughter on "Army Radio Communication." President E. W. Rice, Jr. of the Institute attended the meeting and made a brief address on the great problems facing the country at the present time. Attendance 525.

Seattle.—March 19, 1918, Arctic Building. Paper: "Effects of War Conditions on Cost and Quality of Electric Service" by Lynn S. Goodman and Wm. J. Jackson. Attendance 22.

Spokane.—March 15, 1918. Papers: (1) "Illumination," by T. E. Holsey; (2) "Electric Signs as Advertising Medium" by J. J. Curran; (3) "Voltage Regulation for Lighting" by V. H. Greisser. Attendance 39.

Toronto.—March 15, 1918, Engineers, Club. Paper: "Modern Transformers" by J. J. Frank. Attendance 55.

April 5, 1918, Hydroelectric Laboratories. Illustrated address by Mr. W. P. Dobson on "High-Voltage Phenomena." Attendance 110.

Urbana.—January 18, 1918. Paper: "Some Principles of Illumination and their Application" by J. L. Stair. Attendance 30.

Washington.—April 19, 1918, Cosmos Club Hall. Illustrated lecture by Mr. F. W. Peek, Jr., on "Lightning." Attendance 65.

PAST BRANCH MEETINGS

Colorodo State Argicultural College.—March 11, 1918, Electrical Building. Address by Prof. L. S. Foltz on "Engineering Mathematics." Attendance 20.

Kansas University.—March 21, 1918, Marvin Hall. Addresses as follows: (1) "The Routine of Street Railway Trolley Construction" by Chas. L. Shughart; (2) "Experiences of a Flying Cadet in the Aviation Section" by Lieut. Roy Walker. Attendance 19.

Lehigh University.—April 3, 1918, Physics Laboratory. Papers: (1) "Duties of Naval Consulting Board" by J. W. Richards; (2) "Railroad Electrification" by W. S. Bourlier. Election of officers as follows: president, E. T. Petrik; vice-president, W. B. Shirk; secretary, F. G. Macarow; treasurer, H. S. Bull. Attendance 38.

Michigan Agricultural College.—April 2, 1918. Election of officers as follows: chairman, R. A. Shenefield; secretary, W. A. Siefert. Attendance 14.

University of Missouri.—March 25, 1918, Y. M. C. A. Paper: "Electricity on the Farm" by B. J. George. Attendance 17.

April 8, 1918. Paper: "Heat Flow

and Dissipation in Electric Machines" by D. I. Cole. Attendance 18.

University of Nebraska.—March 13, 1918, Electrical Engineering Laboratory. Paper: "The Regulation of Open-Delta Connected Transformers" by Oskar E. Edison. Attendance 25.

University of North Carolina.—March 20, 1918. Paper: "The Southern Power Company" by R. D. Ballew. Attendance 9.

Ohio Northern University.—March 3, 1918. Papers: (1) "The Technical Story of the Frequencies"; (2) "Design of D-C. Machines." Attendance 15.

March 7, 1918. Addresses as follows: (1) "Induction Motors" by Darlindos Lopes; (2) "The Homopolar Generator" by J. E. Summers. Attendance 21.

Purdue University.—March 19, 1918, Electrical Building. Address by Mr. A. B. Cole on "The Use of Electric Interurban Lines for Freight Hauling as a War Expedient." Attendance 42.

April 2, 1918, Electrical Building. Address by Mr. E. F. Shepard on "Electrolysis." Attendance 88.

April 9, 1918, Electrical Building. Reports of committees. Election of officers as follows: chairman, H. C. Theurk; vice-chairman, C. R. Plummer; secretary, L. A. Malott; treasurer, M. R. Doolittle. Attendance 90.

Rensselaer Polytechnic Institute.—March 27, 1918, Sage Laboratory. Illustrated address by Mr. W. B. Gaylor on "Static Condensers." Attendance 45.

State College of Washington.—March 22, 1918, Mechanic Arts Building Address by Dean L. O. Howard on "Electricity in Mining." Attendance 14.

April 6, 1918, College Gymnasium. Dance to which all engineering students were invited. Attendance 51.

Worcester Polytechnic Institute.—April 5, 1918, Electrical Engineering Building. Paper: "High Explosive Howitzer Shells" by Chester S. Lucas. Attendance 200.

ASSOCIATES ELECTED APRIL 12, 1918

ADAMS, CHARLES SISSON, Chief Electrician, U. S. Naval Experimental Station, New London, Conn.; res., Morgantown, W. Va.

AFFEL, HERMAN ANDREW, Telephone Engineer, American Tel. & Tel. Co., New York; res., 54 Downing St., Brooklyn, N. Y.

ALLEN, ROBERT WHITING, Electrical Engineer, Cutler-Hammer Mfg. Co.; res., 390 22nd St., Milwaukee, Wis.

ASHAUER, FRANK HENRY, Electrical Estimating Engineer, Allis-Chalmers Mfg. Co.; res., 539 67th Ave., West Allis, Wis.

ASHE, MICHAEL JOHN, Asst. Engineer, Interborough Rapid Transit Co.; res., 952 Freeman St., New York, N. Y.

BAIRD, JOHN ELLWOOD, Telephone & Telegraph Engineer, Western Union Tel. Co., New York; res., 81 Fort Green Place, Brooklyn, N. Y.

BARNES, MARION S., Commercial Dept., General Electric Co., San Francisco; res., 2521 Dana St., Berkeley, Cal.

BASON, GEORGE OR, Engineering Dept., General Electric Co., New York; res., 920 E. 10th St., Brooklyn, N. Y.

*BEHRINGER, CHARLES RUSSELL, Standardizing Laboratory, General Electric Co., Schenectady; res., 819 Chestnut St., Utica, N. Y.

*BENHAM, HARRISON MERWIN, Division Constructing Supervisor, New York Telephone Co., Newark; res., 20 Laurel Ave., Irvington, N. J.

BERGMAN, GEORGE E., Sub-Foreman, Electrical Construction, Puget Sound Traction, Light & Power Co.; res., 4317 Phinney Ave., Seattle, Wash.

BLATHERWICK, AUBREY B., Electrical Estimator, U. S. Navy Yard, Puget Sound; res., Bremerton, Wash.

BOISEN, ROBERT L., Supt., Ladysmith Lighting Co., Ladysmith, Wis.

BOLIBAUGH, CHARLES GODFREY, Correspondent, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 820 Wallace Ave., Wilkinsburg, Pa.

BONAMY, LEO J., Chief Electrician, Detroit Screw Works; res., 372 Jay St., Detroit, Mich.

*BONNETT, LELAND BREWER, Electrical Engineer, General Electric Co.; res., 310 Parkwood Blvd., Schenectady, N. Y.

BONOMI, FELIX ARISTIDE, Telephone Circuit Engineer, Western Electric Co.; res., 2245 Bathgate Ave., New York, N. Y.

BRAUND, FRANK WILLIAM, Chief Operator, Substations & Battery Plants, Cleveland Railroad Co.; res., 15718 Grovewood Ave., Cleveland, Ohio.

BRIGGS, ELNATHAN E., Electrical Designer & Inspector, Aberthaw Construction Co., Boston; res., 7 Range Road, Nahant, Mass.

BRIGGS, HARRY B., JR., Chief Draftsman (Electrical), William Cramp & Sons; res., 1450 N. 62nd St. Philadelphia, Pa.

*BROOKS, HENRY WARREN, President & Gen. Manager, Steam & Electrical Machinery Co.; res., 2109 Sixth St., Bay City, Mich.

BROWN, LOUIS EMERY, Sales Engineer, Westinghouse Elec. & Mfg. Co.; res., 70 Hillcrest Apts., Salt Lake City, Utah.

BURNS, ROBERT O., JR., Engineer, Western Electric Co., New York; res., 191 Steuben St., Brooklyn, N. Y.

*CALDERWOOD, EVERETT MORSE, The Pacific Tel. & Tel. Co.; res., W. 27 26th Ave., Spokane, Wash.

CAMPION GEORGE H., Automatic Telegraph Dept., Western Union Telegraph Co.; res., 180 N. Leclaire Ave., Chicago, Ill.

CARLSON, EDWARD C., Telephone Engineer, Engineering Dept., New York Telephone Co.; res., 208 E. 53rd St., New York, N. Y.

*CARPENTER, ARTHUR B., Manager, Southwark Mfg. Co., Camden; res., 308 8th Ave., Hadden Heights, N. J.

CATHERWOOD, WILLIAM S., JR., Electrical Contractor, Metropolitan Engineering Co.; res., 1127 Bergen St., Brooklyn, N. Y.

*CHAFFEE, JAMES W., Patent Attorney, Cutler-Hammer Mfg. Co.; res., 151 13th St., Milwaukee, Wis.

CHEVERTON, JAMES ARTHUR, Electrical Engineer, Milwaukee Electric Railway & Light Co.; res., 143 4th St., Milwaukee, Wis.

CLAPHAM, HERBERT EDWARD, Electrical Laboratory Asst., Automatic Electric Co.; res., 658 W. 61st Pl., Chicago, Ill.

*CLARKE, FRED, Traffic Engineering Dept., American Tel. & Tel. Co., New York; res., 174 Park Ave., Leonia, N. J.

COLE, HUBERT M., Switchboard Wireman, United Electric Light Co.; res., 107 N. Main St., Springfield, Mass.

CRANSTON, ROBERT WALKER, Asst. Supt. of Substations, Territory B, West Penn Power Co., Pittsburgh; res., 408 Whitney Ave., Wilkinsburg, Pa.

DANIELS, HENRY, 2nd Lieut., Signal Reserve Corps, U. S. A.; res., 47 Humboldt Ave., Boston, Mass.

DIKEMAN, HARRY CLIFFORD, Engineering Dept., New York Telephone Co., New York,; res., 81 S. Berger Place, Freeport, L. I., N. Y.

DI PIETRO, VINCENT, Engineering Dept., Western Electric Co.; res., 2121 Belmont Ave., New York, N. Y.

*DONNELLY, AUGUSTINE LEO, Testing Engineer, The Philadelphia Electric Co.; res., 1809 Vine St., Philadelphia, Pa.

DOWMAN, WILLIAM, Engineering Inspection Dept., Western Electric Co., New York, N. Y.; res., 820 Massachusetts Ave., Cambridge, Mass.

DRAKE, CLYDE, Inspection Engg. Dept., Western Electric Co., New York, N. Y.; res., 329 Lyndhurst Ave., Lyndhurst, N. J.

DRAPER, GEORGE WM. EUGENE, Engineering Dept., General Electric Co.; res., 473 West 158th St., New York, N. Y.

DUNCAN, JAMES McA., Manager, Pittsburgh Office, Westinghouse Elec. & Mfg. Co., Union Bank Bldg., Pittsburgh, Pa.

DUNKELBERGER, LLOYD ELMER, Testing Engineer, Williamsburg Pr. Sta., Brooklyn Rapid Transit Co.; res., 447 Greene Ave., Brooklyn, N. Y.

EDELSTEIN, JACOB EDWARD, Engineer, Distribution Dept., Northern States Power Co., Minneapolis; res., North Branch, Minn.

EDWARDS, WILLIAM W., Instructor, Steam Power Plant & Automobile Engg., Wentworth Institute, Boston; res., Brookline, Mass.

EIDAM, EDWARD G., Asst. Chief Engineer, Stromberg-Carlson Tel. Mfg. Co.; res., 85 Middlesex Road, Rochester, N. Y.

ELDRIDGE, HARRY WOOD, Engineering Dept., New York Telephone Co., New York; res., 505 Park Ave., E. Orange, N. J.

*ELSASSER, HENRY WOLFGANG, Engineering Dept., American Tel. & Tel. Co.; res., 302 W. 109th St., New York, N. Y.

FARLINGER, WILLIAM H., Engineering Dept., New York Telephone Co., New York; res., 632 Carlton Ave., Brooklyn, N. Y.

FELDER, SAMUEL IRA, Engineering Dept., New York Telephone Co.; res., 160 Claremont Ave., New York, N. Y.

FERGUSON, JOHN GILBERT, Telephone Engineer, Western Electric Co.; res., 215 W. 23rd St., New York, N. Y.

FERRERI, PETER, Asst. Electrical Engineer, Interborough Rapid Transit Co., New York; res., 55 Hanson Place, Brooklyn, N. Y.

FICH, MARCUS, Engineering Dept., New York Telephone Co.; res., 3204 Hull Ave., New York, N. Y.

FINK, WALTER, Master Mechanic & Electrical Engineer, Austin Street Railway Co.; res., 709 West 7th St., Austin, Texas.

*FISHER, JOHN MCFARLAND, Ford City, Pa.

FITCH, HOWARD S., Asst. System Operator, West Penn Power Co.; res., 7514 Hamilton Ave., Pittsburgh, Pa.

FRANSSON, FRANS JOEL, Research Student, Mass. Inst. of Technology, Cambridge, Mass.

FRASE, JOHN MACCLAIN, Electrical Salesman & Engr., National Board of Fire Insurance Underwriters; res., 622 3rd St., Ft. Wayne, Ind.

FRAZIER, GEORGE ALEXANDER, Service Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1038 Penn Ave., Wilkinsburg, Pa.

FREED, LORING, Statistician, Toledo Railways & Light Co.; res., 228 Irving St., Toledo, Ohio.

FRENCH, HENRY G., Designing Engineer, Switchboard Dept., General Electric Co.; res., 114 Waverley Place, Schenectady, N. Y.

FRISCH, WILLIAM F., Asst. Managing Engr., Transformer Dept., General Electric Co., Ft. Wayne, Ind.

GETTINGER, RALPH F., Service Engineer, Service Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

GIBBON, CHARLES ORLANDO, Elec. Engg. Laboratory Asst., Mass. Inst. of Technology, Cambridge; res., 132 Hemenway St., Boston, Mass.

GOODWIN, EDGAR PALMER, Telegraph Development Engineer, Western Electric Co.; res., 1461 Bryant Ave., New York, N. Y.

GREEN, RULON JAMES, Engineering Dept., General Electric Co., Boston; res., 188 Powder House Blvd., W. Somerville, Mass.

GREENE, SAMUEL EARLE, Electrical Engineer, General Electric Co.; res., 73 Edward Ave., Pittsfield, Mass.

*GURUEE, DE BAUM, Engineering Dept., New York Telephone Co., New York; res., 471 McDonough St., Brooklyn, N. Y.

GUST, RICHARD H., Equipment Asst. Engr., Mountain States Tel. & Tel. Co.; res., 1101 S. Emerson St., Denver, Colo.

HAESLER, GEORGE M., Electrical Draftsman, L. K. Comstock & Co., New York; res., 1323 Spruce St., Morris Park, L. I., N. Y.

HALL, GERALD RUSSELL, Canadian General Electric Co.; res., Apt. 4, 27 Christie St., Toronto, Ontario, Can.

HARRER, WILL J., Gen. Foreman, Transformer Testing Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Turtle Creek, Pa.

HAWLEY, HARRY GILL, Laboratory Asst., Hydro-Elec. Power Comm.; res., 62 Thorold Ave., Toronto, Ont.

HEADLEY, WILLIAM EDWARD, Operating Engineer, Missoula Light & Water Co.; res., 736 Vine St., Missoula, Mont.

HEALD, GLEN D., Telephone Engineer, American Tel. & Tel. Co., New York, N. Y.; res., 39 North Arlington Ave., E. Orange, N. J.

HEISER, CHARLES E., Asst. to Elec. Engr., Motive Power Dept., Philadelphia & Reading Railway Co.; res., 142 W. Greenwich St., Reading, Pa.

HELLMAN, CHARLES F., Elec. Winding & Insulation Expert, General Electric Co.; res., 1515 Swinney Ave., Ft. Wayne, Ind.

HELM, EDWIN GARVIN, Electrician Foreman, Sanderson & Porter Construction Dept., Potomac Light & Power Co., Martinsburg, W. Va.

HERTZ, ADOLPH, Statistician, New York Edison Co.; res., 302 Central Park West, New York, N. Y.

HICKLIN, JOHN WILLIAM, Lighting Engg. Dept., General Electric Co.; res., 7 Spruce St., Schenectady, N. Y.

HIGBEE, RAY PAGE, Electrical Engineer, Otis Elevator Co., 26th St. & 11th Ave., New York, N. Y.

HILBORN, HERBERT HEDLEY, First Asst. Elec. Engr., Brooklyn Rapid Transit Co.; res., 511 Argyle Road, Brooklyn, N. Y.

HILLOCK, EDWARD H., Power Engineer, New York & Queens Electric Light & Power Co.; res., 233 Nott Ave., Long Island City, N. Y.

HOCH, ALBERT J., Engineering Dept., New York Telephone Co.; res., 78 Riverside Drive, New York, N. Y.

HOFFER, LEROY H., Electric Welding, Metropolitan Engineering Co., Brooklyn; res., Nyack, N. Y.

HOGAN, DANIEL JOSEPH, Storekeeper, Electrical Apparatus & Parts, New York Edison Co., New York; res., 256 6th Ave., Astoria, L. I., N. Y.

HOLMES, HENRY S., Electrical Engineer, Metropolitan Engineering Co., Brooklyn; res., 600 W. 192nd St., New York, N. Y.

HORNBECK, HARRY WILLIAM, Engineering Inspection Dept., Western Electric Co., New York, N. Y.; res., 207 Lexington Ave., Passaic, N. J.

HUMPHREY, ARTHUR GOVE, Telephone Engineer, Western Electric Co., New York, N. Y.; res., 34 Kenilworth Place, Orange, N. J.

HUEBNER, CHRISTIAN A., Sales Engineer, Westinghouse Elec. & Mfg. Co.; res., 617 Foreland St., N. S., Pittsburgh, Pa.

*HUEY, GEORGE WILLIAM, Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

HYER, RAYMOND G., Electrical Construction Engr., Westchester Lighting Co.; res., 30 No. 9th Ave., Mt. Vernon, N. Y.

ILGNER, HOWARD F., Engineer in charge of Illumination, Bureau of Illumination Service; res., 493 Murray Ave., Milwaukee, Wis.

ISBELL, DONALD D., Engineering Dept., Electric Storage Battery Co.; res., 3118 N. Broad St., Philadelphia, Pa.

JAMES, ARTHUR EDWARD, Electrical Mechanic, Washington Water Power Co.; res., 1120 E. 38th Ave., Spokane, Wash.

JENKINS, REGINALD THOMAS, Telephone Transmission Engineer, Western Electric Co.; res., 125 St. Ann's Ave., New York, N. Y.

JENSEN, LUDWIG, Switchboard Operator, Light & Power Substations, New York Edison Co., New York; res., 358 41st St., Brooklyn, N. Y.

JENSEN, OSCAR E. R., Foreman Draftsman, Interborough Rapid Transit Co., New York; res., 621 14th St., College Point, L. I., N. Y.

JOHNSON, ALEK, Elec. Instrument Tester, Testing Bureau, Transit Development Co.; res., 505 51st., Brooklyn, N. Y.

JOHNSTON, ALEXANDER CHARLES, Sales Dept., Canadian Westinghouse Co. Ltd.; res., 92 Farnham Ave., Toronto, Ont.

JONES, HARRY EVAN, Telephone Engineer, Mountain States Tel. & Tel. Co.; res., 366 S. Sherman, Denver, Colo.

JONES, RICHARD HENRY, Research Asst., Electrical Laboratory, Univ. of Wisconsin; res., 916 Lake Court, Madison, Wis.

JONES, ROBERT A., Power & Mining Engg. Dept., General Electric Co.; res., 842 Union St., Schenectady, N. Y.

JONES, WILLIAM OSSO, Testing Dept., General Electric Co.; res., 514 Rugby Road, Schenectady, N. Y.

*JOUBERT, LLOYD P., Wiring Draftsman, City Light Dept.; res., 7031 19th Ave., N. E., Seattle, Wash.

KAHN, LUCIEN, Foreman Regulator, Substations, New York Edison Co.; res., 898 Eagle Ave., New York, N.Y.

KANE, EDGAR VINCENT, Industrial Heat ing Engineer, Milwaukee Electric Railway & Light Co.; res., 2023 Grand Ave., Milwaukee, Wis.

KERR, MARK B., Engineer, Telegraph Development Div., Western Electric Co.; res., 12 Charles St., New York, N. Y.

KLEIN, EDWARD, Production Manager, P. H. Klein, Jr., Ltd., Montreal; res., 390 Prince Albert Ave., Westmount, P. Q., Can.

KOENIG, HERMAN CHARLES, Chief Technical Assistant, Electrical Testing Laboratories, New York, N. Y.; res., 1220 Park Ave., Hoboken, N. J.

LANDT, NEWTON ALLISON, Supt., Sou-htern Wisconsin Power Co. Substation; res., 526 W. Conant St., Portage, Wis.

LANPHIER, BASIL, Asst. Engineer, Interborough Rapid Transit Co., New York; res., 50 Fort Greene Place, Brooklyn, N. Y.

LARSEN, LEONARD ENGEBRET, Station Foreman, Montana Power Co.; res., 201 E. 8th St., Anaconda, Mont.

LECLAIR, CHARLES, 1020 Main St., Peekskill, N. Y.

LEMMON, VERNON WILBUR, Telephone Engineer, American Tel. & Tel. Co., New York, N. Y.; res., 9 Summitt St., E. Orange, N. J.

LEWIS, JOSEPH WALTERS, Sales Dept,. Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 403 Hay St., Wilkinsburg, Pa.

LINDSAY, RODERICK O., Operating Engineer, Lake Coleridge Power Station, Addington; res., "Sheperton," Idris Road, Fendalton, Christchurch, N. Z.

LIVINGSTON, PAUL CLARENCE, Substation Operator, Syracuse Lighting Co.; res., 120 Manilla St., Syracuse, N. Y.

LONGTIN, OSCAR EDWIN, In charge of P. H. No. 3, San Joaquin Light & Power Co., North Fork, Cal.

LORENTZ, HENRY E., Asst. Chief Draftsman, New York Telephone Co.; res., 74 West 165th St., New York, N. Y.

LUTHER, ALBERT L., Hydro-Electric Operator, Southern California Edison Co., Big Creek, Cal.

MAC FARLAND, HERBERT DUDLEY, Electrical Inspector, Westchester Lighting Co.; res., 39 South 1st Ave., Mt. Vernon, N. Y.

MAGEE, RALPH R., Salesman, Westinghouse Electric & Mfg. Co., New York, N. Y.; res., 35 N. 9th St., Newark, N. J.

MANN, ROBERT C., Division Electrical Engineer, Mountain States Tel. & Tel. Co.; res., Hall Hotel, Denver, Colo.

MARR, ARTHUR PHELPS, Consulting Electrical Engr. & Attorney, 41 Park Row, New York; res., 1199 Carroll St., Brooklyn, N. Y.

MARTINI, UMBERTO, Electrical Engineer-Technical Manager, Societa Forze Idrauliche della Sila, Via P. E. Imbriani 39, Naples, Italy.

MAY, CHARLES WILLIAM HENRY, Assistant Electrical Engineer, Philadelphia & Reading Coal & Iron Co., Pottsville; res., 107 Paxton Ave., Schuylkill Haven, Pa.

MAYER, JOSEPH NELSON, Technical Assistant, Electrical Testing Laboratories, New York, N. Y.; res., Main St., Millburn, N. J.

McCAIN, MAHLON, Partner, Austin-McCain Co.; res., 1028 Knox Ave., Spokane, Wash.

McCANDLESS, EVERETT, Asst. Supt., Testing Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 402 East End Ave., Pittsburgh, Pa.

McCUSKER, BARNUM C., Engineering Dept., New York Telephone Co., New York, N. Y.; res., 232 N. 22nd St., E. Orange, N. J.

McLAURIN, DUNCAN S., Fire Protection Engineer, Arkansas Actuarial Bureau; res., 2102 Spring St., Little Rock, Ark.

MEAGHER, GEORGE LE ROY, General Foreman of Shops, City Lighting Dept.; res., 2211 15th St. S., Seattle, Wash.

MENKEL, HARRY S., Telephone Engineer, New York Tel. & Tel. Co.; res., 2983 Briggs Ave., New York, N. Y.

*MILBURN, WILLIAM RYLAND, Engineering Dept., Cutler-Hammer Mfg. Co.; res., 3400 Wells St., Milwaukee, Wis.

MILLAR, WENDELL KENT, Hydro-Elec. Station Operator, Southern California Edison Co., Power House No. 2, Big Creek, Cal.

MILLER, JESSE E., General Foreman, Meter & Testing Dept., Milwaukee Electric Railway & Light Co.; res., 785 34th St., Milwaukee, Wis.

MONTGOMERY, L. J., Asst. Gen. Sales Agent, N. Y. & Queens Electric Light & Power Co., Long Island City; res.. Elmhurst, N. Y.

*MOODY, RALPH EDMUND, Valuation Engineer, Milwaukee Electric Railway & Light Co.; res., 627 Stowell Ave., Milwaukee, Wis.

MORGAN, WILLIAM A., JR., Engineering Dept., New York Telephone Co., New York, N. Y.; res., 310 First St., Westfield, N. J.

MORRIS, ROBERT W., Engineering Dept., American Tel. & Tel. Co., New York; res., Roslyn Estates, Roslyn, L. I., N. Y.

MUTH, ARNOLD J., Construction Engineer, Minnesota Utilities Co., Chisholm, Minn.; res., 1046 Wisconsin Ave., Oak Park, Ill.

NEAL, ROBERT ABBOTT, Asst. to Manager, Switchboard Section, Supply Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

*NOBLE, CLAUDE STRATTON, Load Dispatcher, Puget Sound Traction, Light & Power Co.; res., 6329 17th Ave. N. E., Seattle, Wash.

NOLLER, CHARLES WILLIAM, Technical Assistant, Electrical Testing Laboratories; res., 849 West End Ave., New York, N. Y.

NORDENSWAN, ROBERT, Telephone Engineer, Western Electric Co.; res., 393 Edgecombe Ave., New York, N. Y.

OGDEN, CLARENCE E., President & Treasurer, Automatic Electrical Devices Co.; res., 1740 E. McMillan St., Cincinnati, Ohio.

O'NEILL, H. W., Patent Attorney, Western Electric Co., New York; res., 946 52nd St., Brooklyn, N. Y.

PAIGE, NATHANIEL FISH, Executive Office, General Electric Co., New York; res., 115 Edgemont Road, Upper Montclair, N. J.

PAQUETTE, PERCY CARLTON, Telephone Engineer, Engineering Dept., American Tel. & Tel. Co., New York, N. Y.; res., 47 Sanford St., Dover, N. J.

PARK, CHARLES D., Asst. Meter Specialist, General Electric Co., New York; res., 682 St. Johns Place, Brooklyn, N. Y.

PAWLICK, OTTO A., Telephone Engineer, Western Electric Co., New York, N. Y.; res., 107 Halsey St., Newark, N. J.

PETERSEN, HANS, Asst. Chief Draftsman, Cutler-Hammer Mfg. Co.; res., 737 56th St., Milwaukee, Wis.

PETRIE, JAMES MACFARLAN, Supt., Utilities Development Corp., Edwardsport, Ind.

PHILPOTT, HENRY EDWIN R., Operator, Lake Coleridge Main Substation, Addington; res., 164 Lincoln Road, Christchurch, N. Z.

PRESCOTT, GEORGE ARNOLD, Electrician, Fore River Plant, Bethlehem Steel Corp., Quincy; res., 230 Middle St., Braintree, Mass.

*PUMPHREY, RAY EDGAR, Elec. Engr., Apparatus Engg. Dept., General Electric Co.; res., 431 W. Jefferson St., Ft. Wayne, Ind.

RALSTON, THOMAS N., Service Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 505 Holmes St., Wilkinsburg, Pa.

REID, E. J., Asst Supt. of Operation, Shawinigan Water & Power Co.; res., 419 Notre Dame De Grace Ave., Montreal, Quebec.

REID, PAUL H., Chief Draftsman, Niagara Electro-Chemical Co.; res., 718 Augustus Place, Niagara Falls, N. Y.

RENSHAW, ELBERT N., Plant & Engineering Depts., American Tel. & Tel. Co., New York, N. Y.; res., 8 Park Ave., Elizabeth, N. J.

RHINE, CHARLES PAUL, San Joaquin Light & Power Co., Fresno, Cal.

RICHARDSON, ALLEN HAVEN, Electrical Engineer with Albert S. Richey; res., 202 West St., Worcester, Mass.

RINGSTAD, ERLING, Tester of Elec. Apparatus & Machinery, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 835 Rebecca Ave., Wilkinsburg, Pa.

ROGERS, JAMES BOOTH, Electrical Engineer, South Porto Rico Sugar Co.; res., Ensenada, Porto Rico.

ROSENCRANCE, HARRY L., Engineering Dept., New York Telephone Co., New York; res., 851 Hancock St., Brooklyn, N. Y.

ROWAN, FREDERICK HAROLD, Construction Electrician, Titanium Alloy Mfg. Co.; res., 4205 McKoon Ave., Niagara Falls, N. Y.

RUMSEY, WILLIAM W., Engr. in charge of Constr. & Maintenance, Bureau of Illumination Service; res., 298 15th St., Milwaukee, Wis.

SARGEANT, EDMUND COOK, Sales Engineer, Western Electric Co.; res., 1400 University Ave., New York, N. Y.

*SEACORD, DANIEL FREEMAN, Telephone Engineer, New York Telephone Co., New York, N. Y.; res., 49 Park Ave., Englewood, N. J.

SEEM, RUSSELL WILLIARD, Electrician (Operating), Stanislaus, Tuolumne Co., Cal.

SHAVER, ARLINGTON VERNON, Branch Manager, Indiana Inspection Bureau; res., 1345 Park Ave., Ft. Wayne, Ind.

SIMPSON, ROBERT L., Engineering Asst., New York Telephone Co., New York, N. Y.; res., 143 Delaware Ave., Newark, N. J.

SINCLAIR, CHARLES GOODWIN, JR., Engineering Dept., New York Telephone Co., New York, N. Y.; res., Towaco, N. J.

SLOUGH, FRANK M., Patent Attorney & Development Engr., Stromberg-Carlson Tel. Mfg. Co.; res., 7 Farrington Place, Rochester, N. Y.

SMITH, RAY, Supt., City of Longmont Electrical Department, Longmont, Colo.

*SMITH, WORTH JAMES, Engineering Dept., New York Telephone Co., New York, N. Y.; res., 136 High St., Montclair, N. J.

SPARKES, HARRY PECKHAM, Instrument Engineer, Detail & Supply Engg. Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

SPEARS, ROBERT LINCOLN, Service Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 424 Campbell Ave., Wilkinsburg, Pa.

ST. CLAIR, ALBERT, Wire Chief, Keystone Telephone Co., Philadelphia; res., 5636 Whitby Ave., West Philadelphia, Pa.

*STACKHOUSE, RAYMOND CHESTER, Switchboard Specialist, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 22 N. Bryant Ave., Bellevue, Pa.

STANDISH, MILES E., Sales Engineer, Mechanical Appliance Co.; res., 395 Summit Ave., Milwaukee, Wis.

*STEINER, CLARENCE RUNYON, Western Electric Co., New York, N. Y.; res., 307 Avon Ave., Newark, N. J.

STEPHENS, CHARLES EDWARD, Acting Manager, Supply Div., Westinghouse Elec. & Mfg. Co., New York; res., 81 Watson Ave., E. Orange, N. J.

STEVENSON, ROBERT R., Asst. Engr., Hydro-Elec. Power Comm. of Ontario; res., 195 Howard Park Ave., Toronto, Ont.

STOELTZING, LEWIS FRANK, Testing Bureau, Brooklyn Rapid Transit Co.; res., 972 Bedford Ave., Brooklyn, N. Y.

STONE, OSBORN BONE, Inspector, South-Eastern Underwriters Association; res., 53 Ponce de Leon Place, Atlanta, Ga.

STOPPLEMANN, FRED HENRY, Switchboard Specialist, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 313 Trenton Ave., Wilkinsburg, Pa.

*TABB, W. T., Engineer, Cutler-Hammer Mfg. Co.; res., 183 14th St., Milwaukee, Wis.

TAYLOR, GEORGE R., Superintendent, Electric Light & Power, City of Medicine Hat, City Hall, Medicine Hat, Alta.

TEMPLETON, W. B., Supt., Long Lake Power Plant, Washington Power Co., Spokane; res., Reardon, Wash.

*TREENE, WILLIAM HAROLD, Designing Engineer, General Electric Co.; res., 41 N. Wendell Ave., Schenectady, N. Y.

*TUCK, ARTHUR ELMER, JR., Construction Foreman, Engineering Dept., General Electric Co.; res., 210 Olney Ave., Philadelphia, Pa.

VARNER, MILTON K., Long Distance Lines Equipment Dept., American Tel. & Tel. Co.; res., 4534 Washington St., St. Louis, Mo.

VELANDER, F. E. H. EDY, Electrical Engr., Research Dept., Mass. Institute of Technology; res., 1200 Massachusetts Ave., Cambridge, Mass.

VOCE, WILLIAM ALBERT, Engineer of Tests (Imperial Ministry of Munitions), Canadian Allis-Chalmers Co.; res., 59 Grenville St., Toronto, Ont.

VOLPE, JOHN S., Electrician, 37 E. Main St.; res., 19 Granite St., Ashland, Ore.

WALTON, EDWIN R., Electrical Dept., Allis-Chalmers Mfg. Co.; res., 1309 Cedar St., Milwaukee, Wis.

WARD, GUY M., Engineer, Street Illumination, City Light Dept.; res., 3716 Sunnyside Ave., Seattle, Wash.

WARD, OWEN MARTIN, Chief Operator, Milwaukee Electric Railway & Light Co.; res., 304 26th St., Milwaukee, Wis.

WEBER, CORNELIUS, Engineer, Vaughn & Meyer; res., 501 Marshall St., Milwaukee, Wis.

WELLS, JOHN DUNLAP, 2ND, Safety Engineer, National Workmen's Compensation Service Bureau; res., 2588 Dexter St., Denver, Colo.

*WHITE, THOMAS KENNETH, Sales Engineer, Westinghouse Elec. & Mfg. Co.; res., 130 W. 123rd St., New York, N.Y.

WILSON, BARRY, Electrical Foreman, Steel Company of Canada; res., Y. M. C. A., Hamilton, Ont., Can.

WITMER, JOHN STEELE, JR., Engineer, Traffic Dept., New York Telephone Co., New York; res., Port Washington, N. Y.

WOLFF, EDWIN E., Engineering Dept., New York Telephone Co., New York; res., 168 Van Houten Ave., Passaic Park, N. J.

WOODS, GEORGE MATTHEW, Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 7163½ Upland St., Pittsburgh, Pa.

ZIEG, CLIFFORD VICTOR, Engineering Dept., General Electric Co., Ft. Wayne Works; res., 1916 Prince St., Ft. Wayne, Ind.

*Former enrolled Student.
Total 208.

ASSOCIATES RE-ELECTED APRIL 12, 1918

DEWHURST, RICHARD MILLER, Asst. Manager of Sales, Standard Underground Cable Co. of Canada; res., Herkimer Apartments, Hamilton, Ontario, Can.

EDWARDS, IRVING W., Lieutenant, Ordnance R. C., U. S. Army, 422 Brown-Marx Bldg., Birmingham, Ala.

ESPENSCHIED, LLOYD, Engineering Dept., American Tel. & Tel. Co., New York; res., 4 Villard Ave., Hollis, N.Y.

HASTINGS, L. B., Inspector, Signal Corps, U. S. A., Dayton; res., 416 Lake St., Kent, Ohio.

JETER, GEORGE GUY, Sales Engineer, Transformer Sales Dept., General Electric Co.; res., 6 Maplewood Ave., Pittsfield, Mass.

McLEAN, GEORGE LEROY, Switchboard Div., Supply Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 7741 Hamilton Ave., Pittsburgh, Pa.

PARROTT, ROBERT PARKER, Sales Engineer, Edison Lamp Works, General Electric Co., Harrison, N. J.; res., 122 E. 34th St., New York, N.Y.

TALBOT, EMMETT D., Engineer, American Tel. & Tel. Co., New York; res., 403 Clermont Ave., Brooklyn, N. Y.

WILLIAMSON, VICTOR B., Engineering Dept., New York Telephone Co., New York; res., 153 Clinton Ave., Jersey City, N. J.

MEMBERS ELECTED APRIL 12, 1918

DONOGHUE, JOHN EDWARD, Gen. Mgr. & Chief Engr., The Electric Light & Power Supply Corp. Ltd., Sydney; res., Rozelle, N. S.W.

EICHERT, WILLIAM, Supt. Meter Dept., Edison Elec. Ill. Co. of Brooklyn; res., 2216 Cropsey Ave., Brooklyn, N. Y.

KENDELL, BURTON W., Engineer, Research Laboratory, Western Electric Co.; res., 523 W. 121st St., New York, N. Y.

KIME, ROBERT ROY, Sales Engineer, Westinghouse Electric & Mfg. Co., New York, N.Y.; res., 258 Hornblower Ave., Belleville, N. J.

PACENT, LOUIS GERARD, Consulting Engineer, 17 Park Place, New York; res., 14 Woodside Ave., Winfield, N. Y.

VOGELSPANG, GEORGE, Electrical Engineer, J. A. P. Crisfield Contracting Co., Waterbury, Conn.; res., 1979 Clinton Ave., New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER APRIL 12, 1918

BLACK, N. HENRY, Master of Science, Roxbury Latin School, Boston, Mass.

HALL, GAYLORD C., Electrical Engineer, Interborough Rapid Transit Co., New York, N. Y.

LEWIS, ARTHUR PARKER, General Devices & Fittings Co., Boston, Mass.

LEWIS, GEORGE EVELINE, Supt. of Hydraulic Plants, Detroit Edison Co., Ann Arbor, Mich.

SCHURIG, O. ROBERT, Consulting Engineering Laboratory, General Electric Co., Schenectady, N. Y.

TENNANT, JOSEPH ALLAN, Consulting Engineer, Tennant-Lovegrove Co., Houston, Tex.

WALDEN, ALBERT E., Supt. & Chief Engineer, Baltimore Co. Water & Electric Co.; member of firm of Wehr & Walden, Baltimore, Md.

WOODWARD, MARK RITTENHOUSE, Lehigh Portland Cement Co., Allentown, Pa.

Correction

EMBREE, CLAYTON J., erroneously listed in March as transferred to grade of Fellow was actually transferred to grade of Member.

RECOMMENDED FOR TRANSFER

The Board of Examiner , at its meetings mentioned below, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

Recommended for Transfer by the Board of Examiners April 1, 1918

To Grade of Fellow

BUSSEY, HENSON ESTES, District Engineer, General Electric Co., Atlanta, Ga.

To Grade of Member

BAKER, GEORGE MILFORD, Sales Engineer,General Electric Co., Pittsburgh, Pa.

CUSHING, IRA M., Consulting Electrical Engineer, General Electric Co., Boston, Mass.

HUSSEY, ABRAM, Supt. of Distribution, Edison Electric Illuminating Co. of Brooklyn, Brooklyn, N. Y.

Recommended for Transfer by the Board of Examiners, April 22, 1918

To Grade of Fellow

BENNETT, EDWARD, Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.

CASTLE, SAMUEL N., Engineer, General Electric Co., New York, N. Y.

DE FORREST, LEE, President, De Forest Radio Telephone & Telegraph Co., New York, N. Y.

HAUSMANN, ERICH, Associate Professor, Physics and Electrical Engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

MAHONEY, JOSEPH N., Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

SANDERSON, CLARENCE H., Assistant Chief Engineer, Havana Elec. Ry., Lt. & Pr. Co., Havana, Cuba.

To Grade of Member

BRUUN, GEORGE T., Assistant Electrical Engineer, H. Koppers Co., Pittsburgh, Pa.

ESPENSCHIED, LLOYD, Engineering Dept., American Tel. & Tel. Co., New York, N. Y.

GOEBEL, GORDON W., Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

MURRAY, JOSEPH N., Electrical Engineer for New York Office, Takata & Co., New York, N. Y.

PATTERSON, EDWARD G., General Superintendent, Canadian General Electric Co. Ltd., Peterboro, Ont.

SCHWARTZ, ELMER H., Electrical and Mechanical Engineer, New York, N. Y.

VASSAR, HERVEY S., Laboratory Engineer, Public Service Electric Co., Newark, N. J.

WOOLFSON, MONROE G., Lieut. U. S. N. R. F., U. S. S. North Carolina, c/o Postmaster, New York.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before May 31, 1918.

Apperson, A. L., Portland, Ore.
Axell, P., E. Pittsburgh, Pa.
Baker, C. W., Hamilton, Ont.
Baker, R. G., W. Lynn, Mass.
Barker, G. N., Portland, Ore.
Barnett, J. T., Pueblo, Colo.
Barrington, E. G., Toronto, Ont.
Beall, C. R.,
Bell, E. B., Schenectady, N. Y.
Bender, A. P., E. Pittsburgh, Pa.
Brady, F. X., Toronto, Ont.
Blue, N. E., Wilmington, Del.

Bothwell, W. J., E. Pittsburgh, Pa.
Bowen, G. H., Jr., Toronto, Ont.
Brock, S. E., Toronto, Ont.
Brown, A., Philadelphia, Pa.
Brown, G. F., (Member), Schenectady, N. Y.
Bunker, F. L., Duquesne, Pa.
Burgess, L. P., New York, N. Y.
Burke, D. J., Syracuse, N. Y.
Burnham, E. J., Schenectady, N. Y.
Burpee, L., Toronto, Ont.
Burr, A. V., Toronto, Ont.
Cadwallader, J., Pittsburgh, Pa.
Cairns, D., New York, N. Y.
Carson, R. B., Peterboro, Ont.
Chadbourne, R. W., Roxbury, Mass.
Chapman, J. F., Pueblo, Colo.
Clark, H. A., Kankakee, Ill.
Chubbuck, L. B., Hamilton, Ont.
Cohen, L. R. S., Portland, Ore.
Cole, G. H., E. Pittsburgh, Pa.
Collins, L. W., (Member), Trinidad, B. W. I.
Cook, D. C., Pueblo, Colo.
Curfman, H. M., Brooklyn, N. Y.
Dallas, H. A., Boston, Mass.
Dandeno, L. G., Toronto, Ont.
Dee, E. L., Salt Lake City, Utah
Defandorf, J. L., Milwaukee, Wis.
Dodd, R. L., Milwaukee, Wis.
Dodds, J. S., Pittsburgh, Pa.
Dodson, M. L., Balboa, C. Z.
Donald, E. D., Toronto, Ont.
Don Carlos, H. C., (Fellow), Toronto, Ont.
Doughty, R. N., Pueblo, Colo.
Drake, H. C., Brooklyn, N. Y.
Duus, H. G., Philadelphia, Pa.
Edgar, A. S., Toronto, Ont.
Edwards, C. W., Cristobal, C. Z.
Everett, L. C., (Member), New York, N. Y.
Fisher, A. H., Toronto, Ont.
Fleischer, T. F., Philadelphia, Pa.
Franklin, A. G. M., (Member), Kristiania, Norway.
Freyeisen, R. H., New York, N. Y.
Frost, C. M., Portland, Ore.
Gaither, R. H., (Member), Shanghai, China
Genor, A. C. Pittsburgh, Pa.
Gilson, R. M., Swissvale, Pa.
Goller, J. R. P., Long Island, N. Y.
Good, P., (Member), London, Eng.
Gorham, C. F., Chicago, Ill.
Graham, A. J., Bluefield, W. Va.
Graham, J. M., Denver, Colo.
Graham, Q. E., Pittsburgh, Pa.
Grosswege, J. B., Wilmerding, Pa.
Gurney, A. F., Roxbury, Mass.
Hallin, F. W., Cristobal, C. Z.
Hancock, R. E., Greenfield, Mass.
Hatori, M., Tokio, Japan
Hecksher, O., Panama, R. P.
Hilton, A. G., Philadelphia, Pa.
Hodges, A. J., Vallejo, Cal.
Holman, H. R., Niagara Falls, N. Y.
Horner, L. O., Toronto, Ont.
Hubbard, R. O., Seattle, Wash.
Huebner, O. E., Toledo, Ohio
Hunter, A. N., Toronto, Ont.
Isakson, D. W., Kennewick, Wash.
Isshiki, R., Schenectady, N. Y.
Iwata, T., Nanaura, Fukuoka-ken, Japan
Jannati, A. S., Toronto, Ont.
Jennings, E. J., Pueblo, Colo.
Johnson, F. A., Coopers, W. Va.
Jones, H. R., E. Pittsburgh, Pa.
Jones, M. F., E. Pittsburgh, Pa.
Jungk, H. G., E. Pittsburgh, Pa.
Keller, E., New York, N. Y.
Keller, W. H., E. Pittsburgh, Pa.
Lafferty, M. L., Norristown, Pa.
Lee, R. G., Toronto, Ont.
Levy, C. C., E. Pittsburgh, Pa.
Loomis, A. O., E. Pittsburgh, Pa.
Lundgren, H. J., Peterboro, Ont.
Lynch, T., Pueblo, Colo.
Mackey, C. M., E. Pittsburgh, Pa.
Madden, J. T., Gatun, C. Z.
Marriman, J. E., Pueblo, Colo.
Martin, W. E., E. Pittsburgh, Pa.
Maschmeyer, A. M. P., Portland, Ore.
Matsumoto, T., Omuta-shi, Fukuoka-ken, Japan
Mayhugh, E. W., Pueblo, Colo.
McBrian, E. W., Washington, D. C.
McFarlane, W., Lanarkshire, Scotland
McKeen, F. S., Seattle, Wash.
McKnight, W. F., Toronto, Ont.
Mignard, L. D., New York, N. Y.
Motter, H. W., York, Pa.
Mulford H. C., Ft. Monroe, Va.
Mulligan, W. H., Toronto, Ont.
Neill, T. W., Coeur d'Alene, Idaho

Nelson, A. L., Schenectady, N. Y.
Nicholls, H., Tulagi, Solomon Islands
Notley, C., Oakland, Cal.
Nutting, P. G., (Member), E. Pittsburgh, Pa.
Ogle, G. M., E. Pittsburgh, Pa.
Ohkohchu, O., Tokio, Japan
Ohtaka, T., Tokyo, Japan
Olaison, C. E., Minneapolis, Minn.
Pearce, A. M., Philipsburg, Pa.
Pitt, E. R., Washington, D. C.
Pomeroy, J. G., (Member), Seattle, Wash.
Pramm, O., Toronto, Ont.
Proebstel, D. W., Portland, Ore.
Rawson, G. W., Seattle, Wash.
Rea, W. B., New York, N. Y.
Rice, E. T., Erie, Pa.
Riley, F. H. M., Milwaukee, Wis.
Rudd, H. H., E. Pittsburgh, Pa.
Samsel. O. F., Pueblo, Colo.
Schoenfeld, O. C., E. Pittsburgh, Pa.
Schoolfield, H. H., (Member), Portland, Ore.
Schwegler, M. D., Toronto, Ont.
Scott, W. C., Plainfield, N. J.
Seddon, F., Toronto, Ont.
Seybold, R., E. Pittsburgh, Pa.
Sharpe, C. B., Toronto, Ont.
Sheppard, C. H., Niagara Falls, Ont.
Shoneaker, G. A., Pueblo, Colo.
Shonerd, R. E., Los Angeles, Cal.
Slattery, R., Panama, R. P.
Smeloff, N., Bridgeport, Conn.
Smith, G. T., E. Pittsburgh, Pa.
Spahr, R. H., Boston, Mass.
Stafford, H. E., (Member), Port Arthur, Ont.
Stafford, R. T., Seattle, Wash.
Stevens, E. A., Jr., Hoboken, N. J.
Stiefel, I. B., E. Pittsburgh, Pa.
Streeter, E. R., Surf Inlet, B. C.
Struthers, A., Yonkers, N. Y.
Summers, H. S., Galveston, Texas
Sweetnam, A. H., (Member), Brookline, Mass.
Tarasoff, P. J., Toledo, Ohio
Taylor, H. B., (Member), E. Pittsburgh, Pa.
Terry, C. A., Gatun, C. Z.
Tetsutaro, M., New York, N. Y.
Thibault, J. T., Panama, C Z.
Thomas, A. H., Philadelphia, Pa.
Thomas, R. E., Camden, N. J.
Thornton, W. N., E. Pittsburgh, Pa.
Tormin, E. B. M., Roxbury, Mass.
Trisler, J., Pueblo, Colo.
Tuttle, W. W., Harper, Wash.
Ward, S. G., Portland, Ore.
Wesley, J., Pueblo, Colo.
White, J. R., Oakland, Cal.
Wilson, G. B., Toronto, Ont.
Wilson, G. C., St. Marys, Pa.
Wilson, J. C., (Member), Milwaukee, Wis.
Wilson, W., Witton, Eng.
Wood, J. J., (Fellow), Ft. Wayne, Ind.
Wyatt, W. A., Boston, Mass.
Total 171.

STUDENTS ENROLLED APRIL 12, 1918

9525 Guest, T. E., Queen's Univ.
9526 Luney, O. S., Queen's Univ.
9527 Kinnard, I. F., Queen's Univ.
9528 Hanley, A. C., Queen's Univ.
9529 Sims, T. A., Queen's Univ.
9530 Stephens, C. B., Queen's Univ.
9531 Wilson, G. G., Queen's Univ.
9532 Rutherford, W. D., Toronto Tech. School
9533 McMakin, C. E., Wentworth Inst.
9534 Keckler, F. A., School of Engg. of Milwaukee
9535 Peterson, A.P., Univ. of Minnesota
9536 Worthman, H., Jr., Lewis Inst.
9537 Bean, R. D., Lehigh Univ.
9538 Petrik, E. T., Lehigh Univ.
9539 Munkelwitz, N. R., Lehigh Univ.
9540 Ortiz, J. A., Lehigh Univ.
9541 Tinker, E. L., Lehigh Univ.
9542 Keith, I., Lehigh Univ.
9543 Jones, G. F., Lehigh Univ.
9544 Lawall, G. R., Lehigh Univ.
9545 Lindsay, R. H., Lehigh Univ.
9546 Frawley, W. E., Jr., Alabama Poly. Inst.
9547 Fisher, J. P., Univ. of Pa.
9548 Rensch, R. H., Armour Inst. of Tech.
9549 Nitka, J., Armour Inst. of Tech.
9550 Fuller, H. H., Univ. of Wisconsin
9551 Plee, L. S., Michigan Agricultural Coll.
9552 Siegel, R. C., Univ. of Wisconsin

9553 Allegretti, A., Lewis Inst.
9554 Shiavitz, A. S., Lewis Inst.
9555 Johnson, R. F., Lewis Inst.
9556 Barnes, H. F., Swarthmore Coll.
9557 Blassingham, L. F., School of Engg. of Milwaukee
9558 Dorpat, M. H., School of Engg. of Milwaukee
9559 Thompson, H. W., Worcester Poly. Inst.
9560 Craig, C.R., Toronto Tech. School
9561 Steinkamp, K. W., Purdue Univ.
9562 Thompsen, S. N., Lewis Inst.
9563 Cutler, C. W., State Coll. of Wash.
9564 Hubbard, F. W., Worcester Poly. Inst.
9565 Hyman, B., Univ. of Toronto
9566 Almquist, P. B., Univ. of Wash.
Total 42.

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street, New York.

C. H. Butz
(former address)
1735 Williams St.,
Denver, Colo.

Carl L. Gerhardt
(former address)
Throop College of Tech.,
Pasadena, Cal.

James Hodge
(former address)
605 Concord Ave.,
Detroit, Mich.

Hamilton James
(former address)
Stuart James & Cooke,
Commonwealth Bldg.,
Pittsburgh, Pa.

J. Arthur Ramsay
(former address)
Y. M. C. A. Bldg.,
El Paso, Texas.

Morris Sheffler
(former address)
202 Riverside Drive,
Apt. 3 Center
New York, N. Y.

Albert D. Silva
(former address)
1st Bat. F. A. O. T. C.,
Ft. Benjamin-Harrison, Ind.

Nathaniel H. Silver
(former address)
522 Colman Bldg.
Seattle, Wash.

Bertrand Smith
(former address)
Sunnyside Mining & Milling Co.,
Eureka, Colo.

E. Lee Smith
(former address)
4417 Forest Ave.,
Kansas City, Mo.

Robert W. Weeks
(former address)
807 West St.,
Wilmington, Del.

Chas. L. Whipple
(former address)
926-8th Ave. North
Great Falls, Mont.

OBITUARY

JAMES A. BARKLEY, electrical engineer, Lincoln, Nebraska, died on April 17, 1918. Mr. Barkley graduated from the University of Nebraska in 1892 and soon after became Division Manager with the Philadelphia Traction Co. with whom he remained five years. He took charge of the building of the first electric railway in Hawaii and later became Manager of the tramways at Port Elizabeth and Cape Town, South Africa Mr. Barkley was an Associate in the A. I. E. E.

CYRIL F. MICKLER, a member of the 37th Engineers died on March 27 at Ft. Myer, Va., after five weeks in the country's service. Mr. Mickler was a former enployee of the General Electric Company and an Associate in the A. I. E. E.

CAPT. HENRY N. BROOKS, Engineer Reserve Corps, died recently in France of pneumonia. Capt. Brooks, previous to entering the service was a consulting engineer with James N. Hatch, Chicago. He was a graduate of Cornell, class of 1888, and was a pioneer in the electrical railway field. He was connected with the electrification of the Philadelphia car lines in 1892 and 93, had operated electric railway property in Florida and was at one time engaged in similar work with Westinghouse Electric and Manufacturing Company. For eight years he was electrical engineer with Sargent and Lundy of Chicago. Capt. Brooks was a son of the late Admiral William B. Brooks of the U. S. N. He was an Associate in the A. I. E. E.

PERSONAL

HENRY D. JACKSON, formerly of Timothy W. Sprague and Henry D. Jackson, Consulting Engineers, 88 Broad Street, Boston, Mass., has joined the organization of Monks & Johnson, Engineers and Architects, 78 Devonshire Street, Boston, as Power Engineer taking charge of their power plant and heating work.

A. P. C. SCHRAMM, who for the last five years has been Chief Engineer of the Klaxon Company, Newark, N. J., has established himself as a Consulting Engineer at 276 Canal St., New York City. He is working in electrical, industrial and efficiency engineering.

CHARLES E. BURGOON has severed his connection with the Sandusky Cement Co. of Cleveland, Ohio, and has entered the Engineering Department of the Air Nitrates Corporation, 360 Madison Ave., New York City.

ACCESSIONS TO THE UNITED ENGINEERING SOCIETY LIBRARY

(From March 1, 1918, to April 1, 1918.)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made. These are taken either from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

A BIBLIOGRAPHY OF THE WAR CRIPPLE.
Compiled by Douglas C. McMurtrie.

THE ECONOMIC CONSEQUENCES OF PHYSICAL DISABILITY.
A Case Study of Civilian Cripples in New York City. By John Culbert Faries.

MEMORANDUM ON PROVISION FOR DISABLED SOLDIERS IN NEW ZEALAND.
By Douglas C. McMurtrie. N. Y. Red Cross Institute, 1918. 11x8 in., paper.

These pamphlets form the first three numbers of the publications of the Red Cross Institute for Crippled and Disabled Men, a series edited by Mr. McMurtrie. The bibliography covers 39 pages and will be further extended by supplements as new material accumulates.

AIDS IN THE COMMERCIAL ANALYSIS OF OILS, FATS.
And their Commercial Products, a Laboratory Handbook. By George Fenwick Pickering. Phila., J. B. Lippincott Co.; Lond., Charles Griffin & Co., 1917. 133 pp., 9x6 in., cloth, $

Intended as a guide in works laboratories. The tests for determining the purity of the substances and their suitability for various purposes are given, together with tables of constants for each. These values, the author states, are here published for the first time.

A MANUAL OF THE PROCESSES OF WINDING, WARPING AND QUILLING
of Silk and other Various Yarns from the Skein to the Loom. By Samuel

Kline, N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1918. 134 pp., 20 illus., 8x5 in., cloth, $2.

The preface announces this as the first American reference book on the technique of these branches of textile manufacture: and states that it is based upon long practical experience.

A SHORT HAND-BOOK OF OIL ANALYSIS.

By Augustus H. Gill. 8th ed. rev. Phila. & Lond., J. B. Lippincott Co., (copyright 1918). 209 pp., 9 illus., 8x5 in., cloth.

This well-known manual is designed to provide a concise account of the methods of applying the usual physical and chemical tests to oils. The eighth edition has been revised, descriptions of some new forms of apparatus included and some minor tests and new methods added.

A SUPPLEMENTARY MEMOIR ON BRITISH RESOURCES OF SANDS AND ROCKS USED IN GLASS-MANUFACTURE;

with Notes on Certain Refractory Materials. By P. G. H. Boswell with Contributions by W. B. Wright, H. F. Harwood and A. A. Eldridge. N. Y. and Lond., Longmans, Green & Co., 1917. 85 pp., 7 pl., 8x6 in., paper, $1.

Supplements the memoir of the same title which was published in 1916. Describes further supplies and treatment of materials, so that the study of British resources of glass-sand is now believed to be fairly exhaustive. A chapter on American high grade sands is included.

AUTOMOBILE WELDING WITH THE OXY-ACETYLENE FLAME.

A Practical Treatise Covering the Repairing of Automobiles by Welding, with a non-technical Explanation of the Principles to be Guided by in the Successful Welding of the Various Metals. By M. Keith Dunham. N. Y., The Norman W. Henley Publishing Co., 1917. 167 pp., 66 illus., 6x4 in., cloth, $1.

A manual for workmen which explains in simple language the principles of welding, and describes in detail their application in automobile repairing.

BROACHES AND BROACHING.

By Ethan Viall. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1918. 221 pp., 188 illus., 9x6 in., cloth, $2.

A summary of the present development of broaching work and machinery, written primarily to enable those interested to judge whether it is applicable to their particular class of work or not, and to provide working directions in the former case. Contents: Broaching and Broaching Tools; Standard Types of Broaching Machines Examples of Pull Broaching Work and Practise; Examples of Push Broaching Work and Practise; The Design of Pull Broaches; The Design of Push Broaches; Making Broaches.

BROWN'S DIRECTORY OF AMERICAN GAS COMPANIES, 1917.

Compiled and Corrected Annually by E. C. Brown. N. Y., The Gas Age, 1917. 897 pp., 11x7 in., cloth, $5.

This edition summarizes the statistics of 1179 manufactured, 768 natural, 134 acetylene and 70 gasoline gas companies, 161 parent or operating companies and 47 public service commissions. An appendix includes the financial data of 277 companies, the officers, directors and committees of gas associations and an alphabetical list of gas association members, with their company and association affiliations.

CHEMICAL PATENTS;

and Allied Patent Problems. By Edward Thomas. Washington, John Byrne & Co., 1917. 58 pp., 9x6 in., cloth, $2.50.

This work is intended to provide a statement of the law of the chemical patents, together with a practically complete list of the cases on which it is based, and of the principal cases intimately related in reasoning to them. Written from the point of view of the patent attorney and the expert witness.

DYES AND DYEING.

By Charles E. Pellew. N. Y., Robert M. McBride & Company, 1918. 274 pp., 24 illus., 3 pl., 8x5 in., cloth, $2.

This book describes the modern dyes in non-technical language, discusses the theory and practise of color dyeing, and describes the methods of dyeing various fabrics and materials. Various methods of coloring objects in patterns are also described. It is intended for use by craftsmen doing small scale work, rather than for professional dyers or dye house chemists.

ESSENTIALS OF VOLUMETRIC ANALYSIS.

By Henry W. Schimpf. 3d ed., rewritten & enl. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 14+366 pp., 61 illus., 8x6 in., cloth, $1.60.

An Introduction to the Subject, Adapted to the Needs of Students of Pharmaceutical Chemistry. Embracing the Subjects of Alkalimetry, Acidimetry, Precipitation Analysis, Oxidemetry, Indirect Oxidation, Idometry, Assay Pro-

cesses for Drugs, Estimaticn of Alkaloids, Phenol, Sugars, Theory. Application and Description of Indicators.

This edition is revised to accord with the new United States Pharmacopoeia, and improved by the additions of many new assay methods.

FARM FORESTRY.

By John Arden Ferguson. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1916. 233 pp., 5 illus., 40 pl., 8x5 in., cloth, $4.25.

A text-book on the care and management of farm woodlots and the utilization of their products, intended for use by students in agricultural colleges.

FRESH WATER BIOLOGY.

By Henry Baldwin Ward and George Chandler Whipple with a collaboration of a staff of specialists. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1918. 1111 pp., 1547 illus., 9x6 in., cloth, $6.

An important attempt to cover North American fresh water life in its entirety in a single volume. In addition to chapters handled by a specialist on each group, there are chapters on general biological topics, and one on the technical and sanitary problems of the subject.

GAS, GASOLINE AND OIL ENGINES.

By Gardner D. Hiscox. rev., enl. and brought up to date by Victor W. Page. 22d ed. N. Y., The Norman W. Henley Publishing Co., 1918. 640 pp., 435 illus., 9x6 in., cloth, $2.50.

A Complete, Practical Work Defining Clearly the Elements of Internal Combustion Engineering. Treating Exhaustively on the Design, Construction and Practical Application of all Forms of Gas, Gasoline, Kerosene and Crude Petroleum-Oil Engines. Describes Minutely all Auxiliary Systems, such as Lubrication, Carburetion and Ignition. Considers the Theory and Management of all forms of Explosive Motors for Stationary and Marine Work, Automobiles, Aeroplanes and Motorcycles; Includes also Producer Gas and its Production.

The present edition of this well known work has been very thoroughly revised throughout, and an attempt has been made to include all recent developments of importance. New tables, formulas and illustrations have been included and obsolete material has been eliminated, except when of historical interest.

HANDBOOK FOR THE .303-IN. VICKERS MACHINE GUN;

(Magazine Rifle Chamber) Mounted on Tripod Mounting, Mark IV. N. Y., George U. Harvey Publishing Co., Inc., 1917. 82 pp., 1 pl., 5x3 in., linen, 50 cts.

A catalogue in pocket size for those who are called upon to use this gun written by a British Army Officer, Edited by Capt. S. A. Dion.

MECHANICAL EQUIPMENT OF SCHOOL BUILDINGS.

By Harold Alt. Milwaukee, The Bruce Publishing Co., (copyright 1916). 111 pp., 160 illus., 11x8 in., cloth, $2.50.

A discussion of the various problems which arise in the design and installation of the equipment for ventilating, heating, lighting, sewage disposal, cleaning, toilets, drinking water, fire protection, etc., by an engineer with experience as a designing and supervising engineer.

MONTHLY COST ACCOUNTING FOR VARNISH PLANTS.

By E. W. Storey. Phila., National Varnish Manufacturers Association, (copyright 1917). 51 pp., 9x6 in., paper, $1.25.

A detailed description of a method prepared at the request of the Nationai Varnish Manufacturers Assoc., which the author believes will be adaptable to any varnish business.

MUSKETRY.

American Edition (303 and 22 Cartridges) Elementary Training, Visual Training, Judging Distances, Fire Direction and Control, Range Practises, Individual & Collective Field Practises. By Captain E. J. Solano. Hand Grenades; Their Construction-Mills, Hales, Pippin Rifle Grenade, Service, Vaneless, Mexican or Tonite, "P" Grenade, Jam Pot, Hair Brush, etc. By Captain S. A. Dion. N. Y., George U. Harvey Publishing Company, Inc., 1917. 258 pp., 72 illus., 5x4 in., linen, $1.

A pocket size book manual for officers and men.

NOTES ON BALLISTICS.

Direct Fire. By Captain George A. Wildrick, High-Angle Fire. By Lieut.-Colonel Alston Hamilton. 2d ed. Fort Monroe, Journal U. S. Artillery, 1917. 99 pp. 9 illus., 2 diagrams, 10x6 in., paper, 50 cts.

Lieut. Wildrick's paper treats the problems that are most likely to be encountered at the battery, showing current methods of applying ballistic data to their solution. Lt.-Col. Hamil-

ton presents the formulas and methods used in ordinary ballistic computations for high angle fire.

OXY-ACETYLENE WELDING PRACTISE.

A Practical Presentation of the Modern Processes of Welding, Cutting, and Lead Burning, with Special Attention to Welding Technique for Steel, Cast Iron, Aluminum, Copper and Brass. By Robert J. Kehl. Chc., American Technical Society, 1918. 102 pp., 111 illus., 8x5 in., cloth, $1.

A well illustrated description of the methods and appliances in use, intended for the workman and superintendent. Contents: Welding Processes; Technique of Oxy-Acetylene Welding; Miscellaneous Oxy-Acetylene Processes; Examples of Automobile Repair; Costs.

PRACTICAL SANITATION.

A Handbook for Practitioners of Medicine. By Fletcher Gardner. St. Louis. C. V. Mosby Company, 1916. 418 pp., 46 illus., 9x6 in., cloth, $4.

This handbook is intended to provide a plain non-technical exposition of the duties of a health officer by one familiar with his needs experienced in the routine and emergencies of the local sanitary service, and published in a single volume. The second edition is thoroughly revised. An appendix gives schemes for sanitary survey of cities, public buildings and schools.

RAILROAD STRUCTURES AND ESTIMATES.

By J. W. Orrock, 2d ed. rev. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1918. 579 pp., 272 illus., 9x6 in., flexible cloth, $5.

The author has rearranged the chapters in this edition to conform approximately with the classification of accounts as prescribed by the Interstate Commerce Commission in 1914, changed the prices to those which ruled in normal times, previous to 1915, has added much new material and, wherever possible, has given unit costs for all items of track work, track structures and buildings. A feature is made of quantities for track material.

REFERENCE NOTES FOR USE IN THE COURSE IN GUNNERY AND AMMUNITION COAST ARTILLERY SCHOOL, 3D ED.

Fort Monroe, Coast Artillery School Press, 1917. 123 pp., 19 illus., 9x6 in., paper, 50 cts.

A brief text book compiled to meet the immediate demands of candidates for commissions in the Second Coast Artillery School at Fort Monroe.

RELIEF FROM FLOODS.

The Fundamentals of Flood Prevention, Flood Protection and the Means for Determining Proper Remedies. By John W. Alvord and Charles B. Burdick. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1918. 175 pp., 53 illus., 9x6 in., cloth, $2.

The authors of this book have not attempted a treatise on flood relief, but have tried to outline briefly the general flood problem in all its many phases, to show what remedies can be applied and to point the way to the selection of the proper works. Technicalities have been avoided with the hope that the matter may be understandable to readers who are not engineers. A table of great floods is given in the appendix.

TECHNICAL MECHANICS.

Statics and Dynamics. By Edward R. Maurer, 4th ed. rev. & enl. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 381 pp., 178 illus., 9x6 in., cloth, $2.50.

A theoretical mechanics written for students of engineering, in which each subject discussed has a direct bearing on some engineering problem. The book thus differs from those commonly called theoretical mechanics, which are generally intended for students of mathematics or physics. It is, on the other hand dissimilar to books commonly entitled applied mechanics.

The fourth edition differs from the third by the addition of 176 more problems and the modification of the articles on axle reactions, efficiency of machines, hoists, gyrostats, kinetics of plane motion, rolling resistance, kinetics of a body with a fixed point, and the dynamics of any motion of a rigid body.

THE CALORIFIC POWER OF FUELS;

with a Collection of Auxiliary Tables and Tables Showing the Heat of Combustion of Fuels, Solid, Liquid and Gaseous. By Herman Poole. 3d ed. rewritten by Robert Thurston Kent. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1918. 10+267 pp., 65 illus., 9x6 in., cloth, $3.

The introduction of new fuels, the improvements in the methods of investigating the calorific power of fuels and the increase in the amount of available accurate data have made it necessary to rewrite the book. The latest researches have been incorporated, inaccurate data occurring in earlier editions have been eliminated and the results have generally been reported in the English system of units instead of in the metric system used in former editions.

THE CHEMICAL CONSTITUTION OF THE PROTEINS.

By R. H. A. Plimmer. Part I Analysis. N. Y. and Lond., Longmans,

Green & Co., 1917. 12+174 pp., 7 illus., 10x6 in., boards, $1.80.

A thorough revision of the earlier editions, with which much new matter has been incorporated. This section discusses the chemical composition of the protein molecule, and is mainly connected with the analysis of proteins. A very complete bibliography is included.

THE ELEMENTS OF RAILROAD ENGINEERING.

By William G. Raymond. 3d ed. rev. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1917. 24+453 pp., 107 illus., 9x6 in., cloth, $4.

This book attempts to describe the fixed portion of a railroad plant and to give the underlying principles of the design of its layout.

The present edition has been largely revised and the introduction has been modified to conform to the progress that has been made in the study of valuation and regulation of utilities, the discussion of engine capacity and the chapters on signalling have been rewritten, and a chapter on the principles of valuation has been added. Contents: Introduction.—Permanent Way.—The Locomotive and Its Work.—Railroad Location, Construction and Betterment Surveys.-Appendix.

THE EXAMINATION OF MILK FOR PUBLIC HEALTH PURPOSES.

By Joseph Race. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1918. 224 pp., 4 illus., 8x5 in., cloth, $1.75.

This volume is primarily intended as a practical handbook for those engaged in the chemical and bacteriological examination of milk. Numerous references to the literature are included.

THE GAS ENGINE HANDBOOK.

A Manual of Useful Information for the Designer and the Engineer. By E. W. Roberts. 9th ed. rewritten & enl. Cincinnati, The Gas Engine Publishing Co., (copyright 1917). 315 pp., 80 illus., 7x5 in., leather, $2.

An epitome of gas engine practise in pocket book form, intended as a handy book of reference. This ninth edition has been revised to show present practise. Contents: Descriptive; Design; Operation, Testing, Selection.

THE PETROLEUM AND NATURAL GAS REGISTER.

A Directory of the Petroleum and Natural Gas Industries in the United States, Canada and Mexico, 1917-1918 ed. N. Y., The Oil Trade Journal. 548 pp., 12x9 in., cloth, $10.

Includes in one directory material on all branches of the petroleum and natural gas industry. The work is based on statements made by officials of the companies listed, and gives the usually needed information as to properties, capital stock, officers, etc.

THE PHYSICAL CHEMISTRY OF THE PROTEINS.

By T. Brailsford Robertson. N. Y. and Lond., Longmans, Green & Co., 1918. 15+483 pp., 8 illus., 9x6 in., cloth, $5.

An endeavor to interpret the physico-chemical behavior of the proteins in the light of the laws of Boyle and of Gay-Lussac, as they have been applied to solutions by Vant't Hoff, and of the Guldbert and Waage Mass-law. Although confined to proteins, the work is a contribution to an analyses of the properties and behavior of colloids in general.

Rewritten from the German edition of 1912, with references to the literature to the middle of 1917.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

OPPORTUNTIES FOR SERVICE

V-353. Wanted: Electrical engineer as assistant to general manager of explosives plant in Ontario. Man with previous experience in manufacture of smokeless powder and chemical knowledge and experience preferred. Must have good executive ability, experience in the handling of men and should be technical graduate. Salary $3000. to $3500. depending upon the man.

V-354. Several young technical men, draft exempt, will find an unusual opportunity with a prominent truck manufacturer to study truck transportation problems and train for executive positions organizing, operating and managing motor truck fleets. Give full qualifications and salary expected.

V-355. Wanted: Young men for sales engineering, productive engineering, and experimental engineering work in large electrical manufacturing firm in Middle West. Applicants must have complete high school training and the equivalent of at least two years technical training, and preferably be technical graduates from university of good standing. In reply state training and experience in detail, salary desired, draft classification and references.

V-356. Graduate electrical engineer wanted, preferably with one or two years' experience, for the sales department of a company devoting its energies to the manufacture of alternating current apparatus. Correspondence confidential. Give all particulars.

V-357. Wanted: Young engineer competent to assist in the design of small and medium sized A-C. induction motors. Location Middle West.

V-358. Wanted: Man who has had some experience in the design and manufacture of starters for automobile engines and generators for automobiles. Location Middle West.

V-359. Wanted: A young electrical graduate, preferably draft exempt for engineering work in the office of electrical engineer for a large street railway system in the Middle West. Prefer man having some experience in Central Station distribution or sub-station design work. Location Kansas City, Missouri.

V-360. Opening with electrical manufacturer for two central station men experienced in motor sales and installation work. Give complete details and salary desired.

V-361. Wanted: Young college graduate familiar with electrical apparatus to perform tests on mine hoists, pumps, fans, compressors, etc., also competent to solve some problems in power transmission. Minimum salary $115. per month.

V-362. Wanted: First-class electrical layout draftsman for large steam power plant design. Location New York City.

SERVICES AVAILABLE

951. Electrical engineer, technical graduate, ten years in charge of electric power work for largest industrial plants, one year on H-T. transformer design, and seven years in the work of public service regulation. Salary desired $5000. Available on one month's notice.

952. Competent designing and construction engineer, with eleven years' experience on steam and hydroelectric power stations, transmission and distribution systems, substations and industrial plants, offers services, which can include tools, equipment and labor. Work may occupy entire or part time. Responsible position considered.

953. Associate professor of electrical engineering in large eastern state college, available after June 1. Experienced in teaching and in practical work. Wishes

to locate in vicinity of industrial activities. Age 33. Unqualified references.

954. Unusual technical services for sale in the southwest. Successful electrical head of eastern technical school of recognized standing removing to southwest in June will consider professional or practical proposals. Graduate prominent midwestern university 1907. Practical experience. Member A.I.E.E. and S.P.E.E. Perfect health. Married. Present salary $2400.

955. Electrical engineering graduate 1917, now a graduate student majoring in electric railways, age 23, in class V of draft, will be available June 12.

956. Executive engineer, E.E., member A.I.E.E. and S.P.E.E., 16 years' experience in testing, designing, commercial engineering, investigating, reporting, lecturing; at present holding executive position with technical college; author of textbook and technical articles; will be open for engagement. Age 40. Minimum salary $4000.

957. Electrical draftsman seeks position in or near New York City. Salary $30. per week.

958. Electrical engineer. Ten years experience in testing, erecting and design with steam railroad and large manufacturing company desires position with construction or operating company, or with sales dept. of manufacturing company.

959. Electrical engineer, technical graduate, thirteen years' experience, two years apprentice, two years draftsman, nine years estimating, designing and construction power stations, substations switchboards, overhead and underground. Has designed stations up to 200,000 Kv-a. Can handle men. Age 34. Position wanted as engineer or salesman. Salary $3,600.

960. Electrical engineer, has proven technical and business ability, well posted on efficient plant methods, and is accustomed to responsibility. Experienced in telephone engineering, heat light and power engineering. Transmission line construction for both classes of the above service, reports, etc. Will be available on reasonable notice. American, married.

961. University professor, age 27, seeks Summer position, preferably in Government work. Is prepared to carry on investigations in electricity, hydraulics, general engineering and physics. Has good command of mathematics and elementary differential equations.

962. Electrical engineering post graduate. Assoc. A.I.E.E. Age 27, single Broad technical and scientific training in insulation and standardized electrical testing, also general electrical and electrochemical engineering. Have had considerable experience in research work. Can give best references as to ability and success. Desire permanent position with opportunity for advancement.

963. Electrical engineer, 38 years of age, married, at present employed by a large company in the East desires a change. Fifteen years' experience in power-house substation, motors, pole lines and interior wiring. Would like superintendency or position as chief electrician of small plant. South preferred. Salary $1800.

964. Technical graduate, age 27, married, six years construction and operation d.c. substations, design and construction catenary overhead, feeder systems and transmission lines, railway valuation. At present design and construction of railway overhead, transmission lines and small a.c. stations. Draft Class IV-A. Available on thirty days' notice. Minimum salary $200.

965. Electrical engineer, technical graduate, with experience in manufacture of electrical machinery and the construction and operation of steam and hydroelectric power plants, available on short notice.

966. Electrical engineer, technical training, past draft age, electrical experience of nine years, electrical laboratory, test and shop experience in electrical machinery, experienced in all phases of construction, maintenance and operation of electrical equipment mills and factories. At present electrical engineer for an eastern state commission. Available at short notice.

967. Chief electrician and practical electrical engineer with twenty-three years' experience desires position. Ten years with one company as chief electrician and electrical engineer; for the past year with one of the largest operating companies in Massachusetts as inspector of electrical and building construction. Available at once. American. Married. Salary $2000.

968. Electrical engineer, technical graduate. Has practical experience; designing engineer with large industrial plant for past eight years. Transmission line construction, light and power. Railroad electrification. de-

sires responsible position requiring executive ability. Age 35. Married.

969. Sales and executive engineer, E.E., member A.I.E.E., eighteen years' experience; apprenticeship in testing practically everything then made by General Electric Company, followed by designing transformers, power-houses. Reorganization and cost work and construction. In charge of manufacture and sales, electric furnaces, both induction and arc. Joint author of book on electric furnaces published by John Wiley. Age 40. Minimum salary $3600. Best of references.

970. Graduate in electrical engineering, correspondence school course. Eight years in charge electrical construction for engineering firm; two years operating in substation; two years' power-plant operation. Desires position where past experience may be of service.

971. Teacher and engineer of wide experience seeks position as assistant professor of electrical engineering. Salary about $2,000. Available immediately.

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SUSTAINED SHORT-CIRCUIT PHENOMENA AND FLUX DISTRIBUTION OF SALIENT-POLE ALTERNATORS

BY N. S. DIAMANT

ABSTRACT OF PAPER

It is shown in Section IV, that with the ordinary field forms met with in practice the resultant flux wave under s. s. c. (sustained short-circuits) will be extremely distorted, see Figs. 16, (4th wave) 23, 27, 27A, etc., for the simple reason that with the very low voltages obtained under such conditions, the fundamental of the B-curve of the field is reduced so much by the armature reaction that the higher harmonics assume a very predominant rôle and become several hundred per cent of the s.s.c. fundamental. See Fig 26 and Tables XI, XII, and XIII.

As a corollary to the foregoing it is found that the B-curve under load will not differ radically from the no-load field form since the fundamental will remain large enough to hold its own. See Fig. 22 and also footnote (4). The cross magnetizing effect of the armature reaction is, of course, to make the B-curve unsymmetrical with respect to the mid-pole axis. Compare Figs. 7 and 22.

The magnetic oscillations are studied not only by means of full-pitch stator coils but also by means of rotor coils No. 7 and 8, Fig. 3, and stator coils No. 9, 10, 11, 12, 15, and 16, Figs. 3 and 3A.

Attention is called to the following facts for which explanations and theoretical proofs are offered.

(1) *The ripples at the crest of the e. m. f.* waves of the stator coils are due not so much to the flux pulsations as to (a), the to-and-fro flux swing across the pole, and (b) the cutting of a B-curve similar to wave (b), Fig. 6. See equations 22, and 23; also Table I and Note A, at the end. Compare Figs. 7 and 2nd wave Fig. 4.

(2) *The most important oscillations set up by the armature reaction* are 4 and 6 times machine frequency for two- and three-phase machines respectively. See supplementary Notes B and C; also Figs 8A, 8B wave lengths marked B and D, and Fig. 5, wave length marked B, and Table I.

(3) *Eccentric rotor sets up pulsations* once in every revolution, under load or at no-load, but none under s.s.c. See Fig. 4, 2nd wave, Fig. 5 wave length marked A, and Figs. 8A, 8B, and 8C. Also see Table I.

(4) *The e. m. fs. and fluxes* for coils No. 10 at the top of a tooth are very much larger than the e. m. fs and fluxes for coil No. 9, at the top of a wedge. See Tables II and III; also Figs. 10, 11, 12.

(5) *The spacing of the ripples of the no-load e. m. fs.* is unequal, contrary to theory. See Fig. 13 and Table IV.

(6) *The e. m. fs. and fluxes* for search coil No. 5, at the bottom of the slot, are larger than the e. m. fs. and fluxes for the coil No. 1 at the top of the slot. See Fig. 7 and Tables V, VI, and XIV.

(7) *The third harmonics e. m. fs.* of the stator search coils increase with the increasing excitation. See Table IX.

(8) *Under s.s.c. there is present some cross-magnetizing armature reaction* which (a), makes crests 1 and 3 Fig. 27, unequal. See Table XV. (b), it shifts the axis of the flux towards the larger crest, Figs. 23, 27, etc., and thus makes angle B, Fig. 27, less than (1/2) A. See Table XIV.

(9) *The agreement between the armature reaction* obtained by subtracting e_r from e_{fo}, (see Figs. 24, 25, 31 and Figs. 16, 27, etc.) and that obtained by subtracting the equation of the s. s. c. waves as given in Tables XI and XII, from corresponding open-circuit e. m. f. equations as given in Tables VII and VIII, is fairly satisfactory. See last column of Table XIII.

(10) *The direct component of the armature reaction of an imperfect two-phase machine* consists of (a) a regular demagnetizing component, plus (b), a transverse or cross magnetizing component in quadrature to (a). See equations 56, 59, etc.

(11) *The analysis of the no-load field form* gives the 3rd, 5th, and 7th harmonics as 5 to 15 per cent but the $(2q \pm 1)$ ths seem to be small.

(12) *The armature current under s.s.c.* is very nearly sinusoidal. See Figs. 15 and 16. Also Table X. The H-curve of armature reaction set up by such a current will be sinusoidal, see equations 32, 33, etc. and succeeding two paragraphs. The B-curve, however, will not be sinusoidal for lack of constancy and uniformity of the permeability at different points of the magnetic circuit, and on account of saturation. See sections III and IV.

I. Introduction

IN A paper dealing with the sudden short circuits of alternators, presented at the Panama-Pacific Convention, in passing, the author called attention to the following[1]: First; that the voltages induced in full-pitch stator exploring coils under sudden short circuits "are not of as simple a form as theory would indicate." Second, that the flux distribution within about one or two cycles, after the short-circuit takes the general shape which it has under steady or sustained short circuit. The e.m.fs. induced in exploring coils placed at the top, middle and bottom of different slots, all, very shortly after the sudden short circuit, assume a very distorted wave form which persists for the whole length of the film, *i.e.*, about 10 or 15 cycles. The above are clearly seen from Figs. 1 and 2[2] which represent the two extreme cases of symmetrical and totally unsymmetrical armature currents.

The ordinary theories of armature reaction or of short-circuit impedance tests, would hardly lead one to expect results which these oscillograms seem to indicate. A number of valuable investigations on the flux distribution[3] at various loads and power

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1. TRANS., A. I. E. E., 1915. Vol. 34, part II, p. 2259.
2. See Table III, p. 2255.
3. *Journal*, *I. E. E.*, Vol. 37, p. 148. G. W. Worrall and F. T. Wall. See Figs. 2 to 7 inclusive.

factors have given results quite consistent with those deduced from the usual theory. The flux distribution was in no case sinusoidal, to be sure, but it never deviated greatly from the no-load field form usually met with in practise. This is clearly

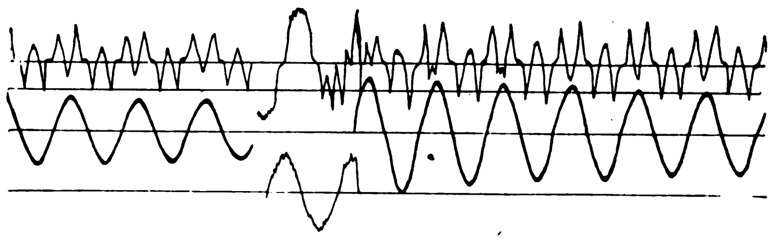


FIG. 1

Oscillogram No. 101. Table III, footnote (2). Machine series Y connected and suddenly short-circuited at its terminals. Field excitation = 5.1 amperes. Speed = 1200 rev. per min. First wave: E_{1T} = e.m.f. induced in coil No. 1, at top of slot. Second wave: armature current. Third wave: phase voltage. Second straight line: calibration for second wave = 293 amperes.

brought out in a series of interesting oscillograms given by W. J. Foster.[4]

In view of the above and the entire lack of reliable data, as to the detailed analysis of sustained short-circuit (s.s.c.) phenomena, the writer could make no more definite statement in the paper referred to, than, that "it would seem that a good way

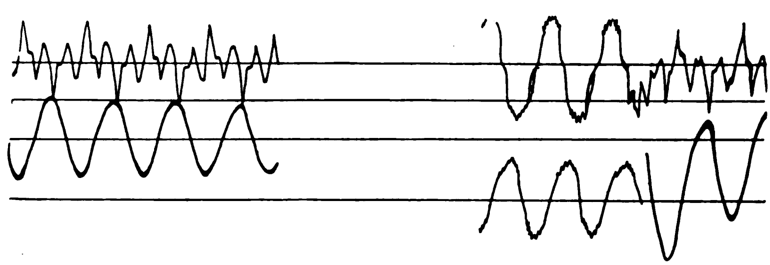


FIG. 2

Oscillogram No. 102. Table III, footnote (2). Machine series Y connected and suddenly short-circuited at its terminals. Field excitation = 5.05 amperes. Normal speed. First wave: E_{3M} = e.m.f. induced in full-pitch coil No. 3 at middle of slot. Second wave: armature current. Third wave: phase voltage. Second straight line: calibration for second wave = 297 amperes.

to study sudden short-circuits was to begin by studying s.s.c. in detail. Although a great deal of work has been done on s.s.c. it is believed that so far little or no attention has been given to the question of flux distribution under such conditions."

4. TRANS., A. I. E. E., part I, 1913, p. 749. See Curves 31, 34, 37, 38, 40, 48, etc.

In the following pages an attempt is made to show that all the complicated phenomena of s.s.c. can be explained by taking proper account of certain details and secondary effects. At the end a critical resumé and discussion of results is given which will enable the reader to obtain some of the principal results of the investigation without studying the paper in detail.

II. Data Relating to the Machine, Exploring Coils, etc.

The machine used for the tests is a standard three-phase, six-pole, revolving field alternator rated at 45 kv-a., 480 volts.

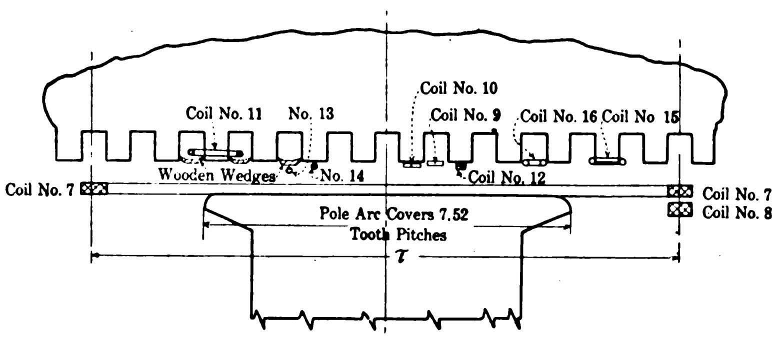


Fig. 3

Coil No. 7: 40 Full pitch concentrated turns.
Coil No. 8: 20 Concentrated turns.
Coil No. 9: 5 Concentrated turns.
Coil No. 10: 5 Concentrated turns.
Coil No. 11: 5 Concentrated turns.
Coil No. 12: 2 Concentrated turns, one on top of other thus having effective pitch of single turn.
Coil No. 13: Single conductor on top of wedge.
Coil No. 14: Single conductor on top of tooth.
Coil No. 15: Single turn around tooth.
Coil No. 16: Single turn around slot.

(278 across phase). It has an amortisseur winding and is equipped with a set of search coils as follows:

Coil No. 1. Full-pitch, 5 concentrated turns at top of slot, right under wooden wedge.

Coil No. 2. Same as No. 1, except that it is $\frac{2}{3}$ pitch.

Coil No. 3. Similar to No. 1, but placed at the middle of the slot.

Coil No. 4. Same as No. 3, except that it is $\frac{2}{3}$ pitch.

Coil No. 5. Similar to No. 1 but placed at the bottom of the slot.

Coil No. 6. Same as No. 5 except that it is $\frac{2}{3}$ pitch.

These coils were placed in different slots. The other search coils are schematically shown and described in Figs. 3 and 3A. The armature winding is of the ordinary double-layer type with a $\frac{2}{3}$ pitch, and it has two circuits which may be connected either in parallel or in series.

In connection with the coils most commonly employed the following notation will be used:

*E_{1T} = e.m.f. induced in coil No. 1. (Subscripts: No. 1 top of slot.)

*E_{3M} = e.m.f. induced in coil No. 3. (Subscripts: No. 3 middle of slot.)

*E_{5B} = e.m.f. induced in coil No. 5. (Subscripts: No. 5 bottom of slot.)

*E_{RF} = e.m.f. induced in coil No. 7, (Subscripts: Rotor full-pitch coil.)

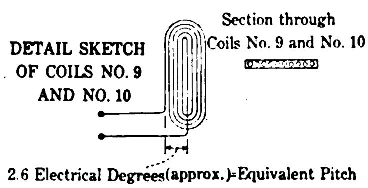


FIG. 3A

*E_{RC} = e.m.f. induced in coil No. 8. (Subscripts: Rotor concentrated coil.)

*E_{TW} = e.m.f. induced in coil No. 9. (Subscripts: Coil at top of wedge.)

*E_{TT} = e.m.f. induced in coil No. 10. (Subscripts: Coil at top of tooth.)

*E_{AT} = e.m.f. induced in coil No. 11. (Subscripts: Coil around tooth.)

*E_{TT2} = e.m.f. induced in coil No. 12. (Subscripts: 2 turns on top of tooth.)

*E_{CTS} = e.m.f. induced in coil No. 13. (Subscripts: Conductor on top of slot.)

*E_{CTT} = e.m.f. induced in coil No. 14. (Subscripts: Conductor on top of tooth.)

B = Flux density as further specified by its subscript.

f = (actual) machine-frequency in cycles per second $= \text{r.p.s.} \times p$.

*All under conditions to be specified.

k = Order of space harmonic. See p. 17 for explanation.
p = Number of pairs of poles.
p_k = Number of pairs of poles of k^{th} space harmonic $= k\,p$
q = Number of slots per pole.
s.s.c. = sustained short-circuit.
τ = Pole pitch in centimeters or inches.
τ_k = Pole pitch of k^{th} space harmonic $= \tau/k$.
$e_{rot.st.}$ = Instantaneous value of rotational e.m.f. induced in stator coil.
$e_{pul.st.}$ = Instantaneous value of e.m.f. induced in stator coil due to pulsations of flux. (In magnitude only.)
$e_{sw.st.}$ = Instantaneous value of e.m.f. induced in stator coil due to to-and-fro swing of flux. (Without change in magnitude.)
$e_{pul.r.}$ = Same as $e_{pul.st.}$ except that it refers to coil on rotor.
$e_{sw.r.}$ = Same as $e_{sw.st.}$ except that it refers to coil on rotor.

III. Flux Distribution at Various Loads and Power Factors

The oscillographic study of flux distribution in alternators and other apparatus by means of exploring coils would have been extremely simple, were it not for the fact that the quantity recorded on the film is not the flux wave in which we are interested but a quantity proportional to its *time rate of change*.

A conductor moving across a magnetic field, constant both in time and space, *i.e.*, a field constant in magnitude and stationary with regard to the pole axis, will have an e.m.f. induced in it which may be designated as motional or rotational e.m.f.; this will be maximum when an element $d\,l$, of the conductor under consideration, its velocity v, and the flux density B_m, all three, are mutually perpendicular. However, without any relative motion between flux and conductor, if the flux enclosed by the circuit varies for any cause and in any manner whatsoever, there will be an e.m.f. induced proportional to the rate of change of flux. This may be called static or variational e.m.f.

Thus in the most general case,[5] which is the one met with in practise, the e.m.f. induced in a conductor or coil is:

$$e_{\text{total}} = e_{\text{motional}} + e_{\text{variational}},$$

where e_{total} is the quantity recorded on the film.

5. See, in this connection, A. Blondel, *Sur l'énoncé le plus général des lois de l' induction*. Compt. Rend. 1914, Vol. 160, Nos. 20 and 22.

The application of the above to the analysis and interpretation of the complex waves obtained under s.s.c. or even the simpler phenomena of open-circuit is difficult. Therefore, it will be well to call attention at first, to some general facts which though not entirely new do not seem to be generally known.

It is clear that the e.m.f. induced in a conductor or a number of concentrated turns (on the armature) will be a true reproduction of the B-curve under the pole, provided the variational e.m.f. were zero—which is seldom the case. The variational or static e.m.f. will depend upon the manner in which B varies with respect to time only. As a result of some valuable researches[6] it has been found that B may vary with respect to time in two ways: First, due to what may be termed the inductor alternator action of the teeth, there may be a *variation in the amount of reluctance* of the magnetic circuit of the machine. This will cause pulsations in the intensity of B and thus an e.m.f. will be induced in the armature coils as well as the pole pieces, yoke, etc. The latter will give rise to parasitic eddy currents which will tend to wipe out the pulsations. Thus, as indicated by theory and as shown by test, the variational e.m.f. due to this cause will be very small (compared to the rotational e.m.f.). Secondly, it has been found that the flux density at any point under the pole may vary due to a *to-and-fro swing* of the flux-wave with respect to the (geometrical) pole-axis. It has been shown by Worrall[6] by trimming the pole-shoes and varying the number of slot-pitches covered by it, that the pulsation is maximum when the pole-arc covers a whole number of slot-pitches, while the flux-swing is maximum when the pole-arc covers (an integer + $\frac{1}{2}$) slot-pitches. This neglects fringing and in the experiments referred to, it seems to hold remarkably well. However, it seems to the writer that fringing should not be neglected since it is not the geometrical tooth or slot but the manner in which the flux is distributed in these that is responsible for the static e.m.f. Thus, his conclusions seem to be correct, except that it would be more rational to consider the effective teeth and slots (so far as flux is concerned).

The study of the experimental results as well as the quantitative expressions developed in the supplementary notes show that the e.m.f. waves of coils No. 7 and No. 8 give chiefly the

6. G. W. Worrall, *Jour., Inst. E. E.*, 1907, Vol. 39, p. 206. Also 1908, Vol. 40, p. 413. Guery, *L' Eclairage Electrique*, 1903, Vol. 36, p. 51. Arnold and La Cour, *Samn. Elek. Vort.*, 1901, Vol. 3, p. 58. K. Simon, *E T. Z.*, 1908, Vol. 27, p. 631. *Electrician*, Vol. 57, p. 581.

e.m.f. due to flux pulsations. See second wave Fig. 4 and Fig. 5. The e.m.f. due to the to-and-fro motion of the flux is given by: (for $x_1 = 0$ see note A)

$$e_{sw.r.} = 2\,N\,l\,q\,\omega\,\epsilon^2\,B_1 \sin\,(4\,q\,\omega\,t) \qquad \textbf{(22)}$$

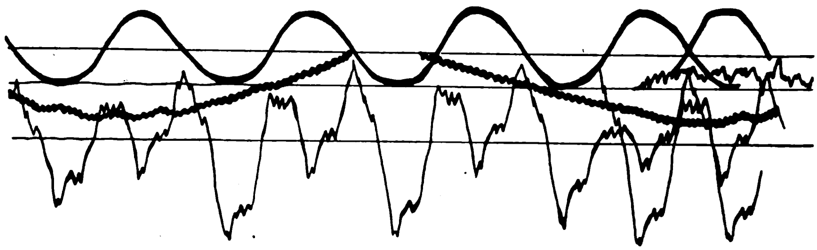


FIG. 4

Oscillogram No. O A 84. Test No. 196. First wave: armature current under s.s.c. at 4.96 amperes field excitation, normal speed and machine connected 2 phase. Third wave: E_{RF} = e.m.f. in full-pitch 40-turn rotor coil No. 7 under same conditions. Second wave: E_{RF} at same excitation and speed at no-load.

and that due to the pulsations of flux by:

$$e_{pul.r.} = 4\,N\,l\,q\,\omega\,\eta\,B_1 \sin\,(2\,q\,\omega\,t) \qquad \textbf{(23)}$$

where η and ϵ are small fractions denoting the amplitude of the variations of flux, in each case. The former would be expected to be small as it involves ϵ^2 and oscillograms give no indication of the existence of ripples of ($4\,q \times$ machine-frequency), as required by (**22**). As seen from Fig. 4, second wave, and Fig. 5, the little kinks in the E_{RF} wave (due to the pulsations

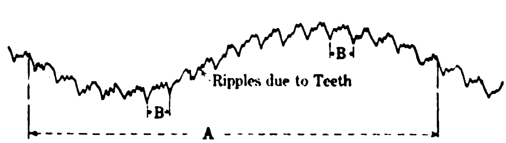


FIG. 5

Oscillogram No. O A 21. Test No. 91. Table I. Machine parallel Y connected and run as synchronous motor. Field current = 4.4 amperes. Line current = 15.5 amperes. Line voltage = 220. E_{RF} = e.m.f. induced in rotor coil No. 7. Note: A = 1080 deg. B = 60 deg.

of flux) under synchronous motor and no-load operation, are fairly small and have a frequency of $2\,q\,f$, *i.e.*, show $2\,q = 24$ ripples per cycle. See Table I, column 6. This is what would be expected from (**23**).

While it is clear that the kinks in the E_{RF} wave, Figs. 4 and 5, are due to the teeth, the long flat superimposed wave having a period A, is believed to be due to the rotor being eccentric with respect to the stator. This explanation seems the more plausible when it is considered that A, Fig. 5, is found to be 1080 electrical degrees, as indicated in Table I column 4;

TABLE I.

Data relating to the e.m.fs. induced in rotor exploring coils under conditions given below.

No. of oscill. / No. of test	E_{RF} / E_{RC}	Field current in amps.	A in degrees see Fig. 5	B in degrees see Fig. 8	No. of ripples per cycle	Freq. in cycles per sec.	Amplitude in max. volts see Figs. 8a, b, c — pos.	neg.	Line current in amps.	Approx. power facto
1	2	3	4	5	6	7	8	9	10	11
				Synchronous Motor Operation						
O A 21/91	E_{RF}	4.4	1080	54.8	24	59.5	0.69	0.82	15.5	1
O A 22/92	E_{AP}*	4.4	1080	60		59.5	0.66		15.2	1
O A 39/115	E_{AP}*	1.0	1080		24	59.5	1.12	mean	79	0.27 lg.
O A 40/116	E_{RC}	8.3	1080	61.3		59.5	1.12	mean	76	0.28 ld.
O A 36/118	E_{RC}			61	24	59.5	0.037	0.053	85.5	0.25 lg.
O A 37/109	E_{RC}	8		60.6	24	59.5	0.037	0.053	71.2	0.24 ld.
				Sustained Short-Circuit. Series Y Connection						
–/164	E_{RF}	5			24	54	0.97 mean			
–/165*	E_{RC}	5			24	50	0.03 mean			
–/166	E_{RC}	3.16			24	52	0.027 mean			
–/167	E_{RF}	3.16			24	52	0.71 mean			
226/–	E_{RF}	5		59.2	24	60				
				Open-Circuit Operation						
–/163	E_{RF}	5				60	2.46			
–/162	E_{RF}	3.16				60	1.94			
–/161	E_{RF}	5				54	2.31			
–/160	E_{RF}	3.16				54	1.98			
O A 24/94	E_{RF}	5	1080	60	24					

*E_{AP} = e.m.f. induced in search coil around pole, right under pole-shoe; this gave practically same results as full-pitch coil and therefore it was disconnected from slip-ring and not used.

i.e., the superimposed wave is found to have under load or at no-load a frequency $(\frac{1}{3})\ f = (1/p)\ f$ = one cycle per revolution.

For a conductor placed at the middle of the pole-arc, *i.e.*, at $x_1 = \pi/2$, Fig. 6, $e_{sw.r.}$ would be maximum and $e_{pvl.r.}$[7] would be zero; *i.e.*, such a conductor would give ripples due to the

7. See equations (**21**) and (**20**) respectively in supplementary notes.

flux-swing only. Attempts were made to take advantage of this but owing to the high centrifugal force it was found difficult to fasten down securely wires at the mid-pole position.

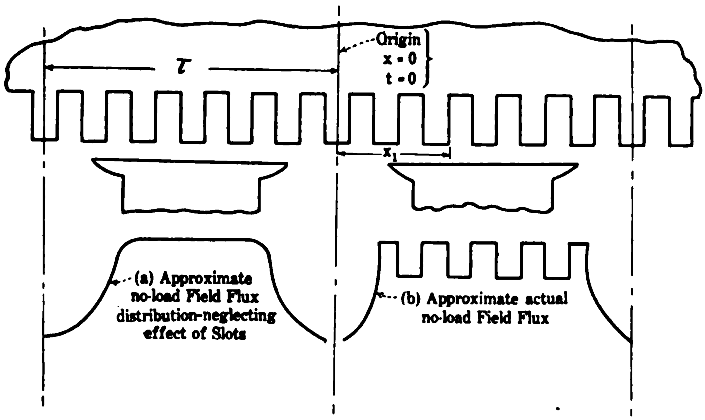


FIG. 6

However, a very good idea of the relative magnitude of the e.m.f. due to flux-swing, can be obtained by studying the e.m.f. waves induced in the stator coils. These will consist of (e_{rot}

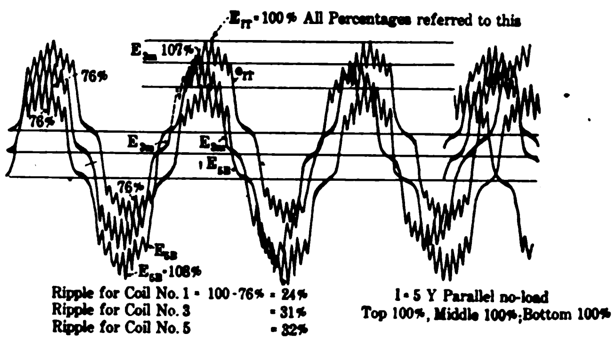


FIG. 7

Oscillogram No. O A 38. Test No. 110. Tables IV, V and VI. Machine run on open-circuit. First wave: E_{1T} = e.m.f. induced in exploring coil No. 1 at top of slot. Second wave: E_{3M} = e.m.f. induced in exploring coil No. 3, at middle of slot. E_{5B} = e.m.f. induced in exploring coil No. 5, at bottom of slot. Speed normal, *i.e.*, corresponding to 60. Excitation = 5 amperes. Same vibrator and resistance in vibrator circuit used for all waves.

$+ e_{pul} + e_{sw}$). As indicated by equations (**7**), (**13**) and (**18**) Note A, e_{pul} will be negligible for a rotor coil placed at the middle of the pole-shoe, *i.e.*, at $x = \pi/2$, or for a stator coil

whenever $x = \pi/2$, see Fig. 6. In other words, e_{pul} will be negligibly small *whenever* $e_{rot.st.}$ is maximum. Thus the ripples at the crest of the e.m.f. wave ($x = \pi/2$) of the stator coils 1, 3 and 5 are due mainly to flux-swing and a comparison of the ripples in them, Fig. 7, with the kinks of the E_{RF} wave, second wave Fig. 4 and Fig. 5, and E_{RC}, Fig. 8a, will show at once that the kinks (due to pulsation) are quite negligible compared to the ripples (due to flux-swing)—especially when it is remembered that coils No. 8 and 7 have many more turns than the stator coils and the volts per centimeter for the calibration of the former is about ten per cent of that for the latter.

The subject of tooth ripples is of great practical importance,

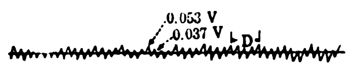


FIG. 8A

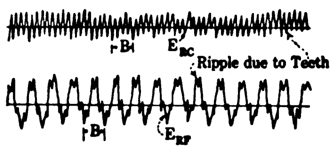


FIG. 8B

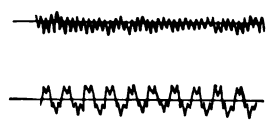


FIG. 8C

Fig. 8a Oscillogram No. O A 36. Table I. Machine run as synchronous motor. Line current 85.5 amperes lag. Line voltage = 200. E_{RC} = e.m.f. induced in coil No. 8. Exactly same wave shape and amplitude obtained in oscillogram No. O A 37 with 71 amperes of leading line current and 238 line voltage.

Fig. 8b Oscillogram No. O A 49. First wave E_{RC} = e.m.f. induced in coil No. 8. B = 60 deg. Second wave: E_{RF} = e.m.f. induced in coil No. 7. B = 60 deg. Machine series Y connected and short-circuited at its terminals. Field current = 5 amperes. Frequency = 54 cycles per second. Resistance in vibrator circuit = 0 ohms and gold-leaf fuses short-circuited.

Fig. 8c Oscillogram No. O A 50. Similar to O A 49 in every respect, except field excitation = 3.16 amperes. Same vibrators used.

not only in case of accurate tests and measurements but also in connection with the operation of large alternators, induction motors, etc. Though effective methods have been developed for their elimination there seems to be lack of general concensus of opinion[8] as to their origin and detailed analysis. In this connection it seems pertinent to ask, whether the ripples are entirely variational in their origin or are they partly motional. The actual flux density in the air-gap has the general form indicated by curve (b) rather than curve (a) Fig. 6. Since the motional

8. S. P. Smith and R. H. Boulding, *Jour.*, *I. E. E.*, 1915, Vol. 53, p. 205. Discussion p. 238. Also see correspondence *Electrician*, June, 1914. Further, see references given under foot-note (6).

e.m.f. will be duplicate of the B-curve, it is clear that the tooth ripples will partly have motional origin, *i.e.*, will be partly due to the cutting of a B-curve like that shown in (b) Fig. 6.

A general idea of the relative importance of the ***tooth kinks in the B-curve*** may be gained from Fig. 9 which is self-explanatory. The flux measurements were obtained by pulling out of the air gap an exploring coil fastened on a piece of cardboard and having a length approximately equal to the axial thickness of the armature core, and a width about 30 per cent of that of a tooth. In the test recorded in Fig. 9, the machine was stationary; in the next one, the rotor was excited and slowly rotated and the following maximum throws of the Grassot fluxmeter were observed.

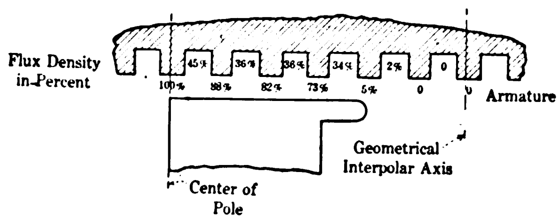


FIG. 9

Flux distribution with the machine stationary as measured by Grassot fluxmeter.

Coil No. 10—coil at top of tooth—maximum deflection = 100 per cent.

Coil No. 9—coil at top of wedge—maximum deflection = 41 per cent.

Coil No. 8—concentrated coil—maximum deflection = 8 per cent

The actual flux density under running conditions was further investigated by means of the exploring coils No. 9, 10 and 11, Figs. 3 and 3A, by taking oscillographic records of the e.m.fs. induced in them under no-load, s.s.c. and synchronous motor operation. The data obtained in this series of tests is brought together in Table II. As seen from Figs. 10, 11 and 12 the E_{AT}, E_{T1} and E_{TW} waves have two prominent crests above, and two below, the zero line, per cycle. These are quite characteristic and are designated as 1st and 2nd positive and 1st and 2nd negative. See Table II, columns 8 and 11. The angular distance between successive + or − crests is designated by α and that between successive positive and negative ones by β. See Fig. 10 and Table II columns 6 and 7.

TABLE II.—Data relating to the e.m.fs. induced in Exploring Coils No. 9, No. 10 and No. 11 (Fig. 3) under open-, sustained-, short-circuit and synchronous motor operation.

No. of oscilograms / No. of test	$E_{A.T.}$ $E_{T.T.}$ $E_{T.W.}$	No load, s.s.c. or synch. mot. / field amperes	Line current in amperes	Approximate power factor leading or lagging	α (in degrees; See Figs. 10, 12, etc.)	β (in degrees; See Figs. 10, 12, etc.)	Consecutive crest values in max. volts per turn: Positive crests 1st	Positive crests 2nd	Negative crests 1st	Negative crests 2nd
1	2	3	4	5	6	7	8	9	10	11
O A 25/95	$E_{A.T.}$	N. L./5	0		118°	61°	1 47	1.39	1.49	1.27
O A 61/172	$E_{T.T.}$	N. L./4.95	0		120.5°	59.5°	0.508	0.422	0.466	0.416
O A 20/90	$E_{A.T.}$	S. M./4.49	15.5	0.95 lg.	117°	59.9°	1.18	1.24	1.02	1.23
O A 27/97	$E_{T.T.}$	S. M./4.24	15.5	1.0	116.5°	62.3°	0.33	0.33	0.38	0.34
O A 27/97	$T_{T.W.}$	S. M./4.24	15.5	1.0	119°	59.4°	0.15	0.16	0.15	0.15 +
O A 23/93	$E_{A.T.}$	S. M./3	18.5	0.81 lg.	113°	65.1°	1.19	1.07	1.05	1.19
O A 28/98	$E_{T.T.}$	S. M./2.9	39.5	0.56 lg.	119°	62.2°	0.24	0.28	0.24	0.29
O A 28/98	$E_{T.W.}$	S. M./2.9	39.5	0.56 lg.	115°	60.9°	0.12	0.14	0.12 +	0.14 +
O A 26/96	$E_{A.T.}$	S. M./	40.7	0.4 ld.	124.8°	58.5°	1.41		1.44	1.47
O A 29/99	$E_{T.T.}$	S. M./5.4	39.5	0.45 ld.	118.4°	62.15°	0.47	0.48	0.48 +	0.48 –
O A 29/99	$E_{T.W.}$	S. M./6.4	39.5	0.45 ld.	119.5°	61.7°	0.19	0.196	0.194	0.194
O A 37/109	$E_{A.T.}$	S. M./8	71.2	0.24 ld.	121.5°	57 3°	1.47	1.47	1.51	1.51
O A 36/108	$E_{T.T.}$	S. M./–	85.5	0.25 lg.	117.5°	63.3°	0.71 +	0.94	0.71 +	1.0 –
O A 41/117	E_{TT2}	N. L./ –	0		117°	62.4°	0.017	0.014		
O A 41/117	E_{TT2}	S. M./ –	24.7	0.93 lg.	116°	61.4°	0.041	0.034		
O A 40/116	E_{TT2}	S. M./–	76	0.26 ld.	120°	61.5°	0.045	0.047	0.045	0.047
O A 39/115	E_{TT2}	S. M./–	79	0.27 lg.	111.5°	62.6°	0.022	0.033	0.022	0.033
		Field amperes	Kind of s.s.c.	Frequency						
O A 61/172	E_{TT}	4.95	Y series	60	118.4°	61.6°	0.23	0.187	0.25	0.187
O A 59/180	T_{TW}	5.0	Y series	60	119°	60.1°	0.18	0.12	0.16	0.12

NOTE: α and β are in terms of machine-frequency. Thus if once cycle at machine-frequency occupies in cms. on the film and α is n cms., then $\alpha = \frac{n}{m} \times 360$ deg.

The peculiar shape of these curves may be explained as follows: As a concentrated coil like No. 9 or No. 10, moves past a (stationary) field pole, the amount of change in the enclosed flux will depend upon the tooth kinks of the B-curve, (b) Fig. 6. If the B-curve were flat topped, see (a) Fig. 6, there would be no change of flux through coils No. 9 or 10 while under the pole-arc. Thus the small ripples in the portion of the B-curve marked β, Fig. 10, are due partly to the bunching of the flux at the teeth and partly due to the flux variations (= pulsations in magnitude, and to-and-fro swing), as already explained. As the coil emerges from under the horn of, say, a north pole and begins to enter the

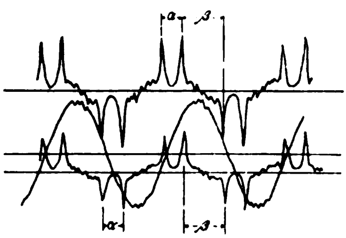


FIG. 10

Oscillogram No. O A 28. Test No. 98, Table II. First wave: E_{AT} = e.m.f. induced in coil No. 11 around tooth. Second wave: volts across the terminals of the machine. Third wave: E_{TW} = e.m.f. induced in coil No. 9 on top of wedge. Machine parallel Y-connected and operated as a synchronous motor. Line current = 39.5 amperes. Line voltage = 212 volts. Power factor = 56 deg. lag. α corresponds to interpolar space. β corresponds to space under pole-arc.

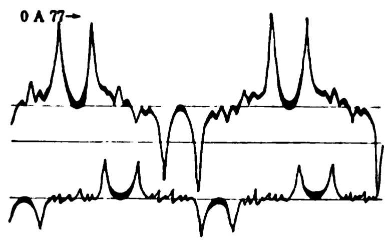


FIG. 11

Oscillogram No. O A 77. Test No. 189. First wave: E_{TT} = e.m.f. induced in search coil No. 10 at top of tooth. Second wave: E_{TW} = e.m.f. induced in exploring coil No. 9 at top of wedge. Machine run at open-circuit and same vibrator and same resistance in vibrator circuit for both waves.

interpolar region and then the tip of the south pole, there will be, two, conparatively large changes in the flux enclosed; these flux changes will give rise to two peaks whose angular spacing α, as seen from Table II is about 60 elec. deg. *i.e.*, α corresponds to the angular distance between two consecutive pole-horns. Evidently these crests should be on the same side of the zero line since one is due to a decreasing flux issuing from a north pole, while the other is due to an increasing flux of opposite polarity.[9]

9. See curve 32 given by W. J. Foster, TRANS., A. I. E. E., 1913, Vol. 32, p. 754.

At first sight it might be expected that the e.m.fs. induced in coils No. 9 and 10 should be similar in shape and equal in amount since the only difference between them is that one is placed on top of a tooth, while the other is on top of a wedge. However, as seen from Table II this is by no means the case; further as

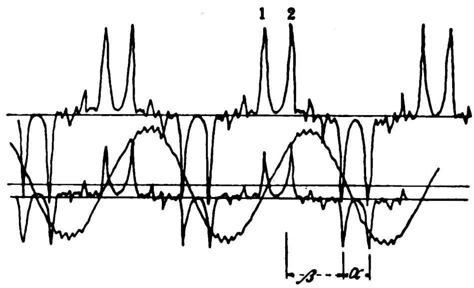


FIG. 12

Oscillogram No. O A 29. Test No. 99. Table II. Machine Y parallel connected and run as a synchronous motor. Field excitation, 6.4 amperes. Line voltage = 237 volts Line current = 39.5. Approximate power factor = 0.45 leading. First wave: E_{TT} = e.m.f. induced in coil No. 10 at top of tooth. Second wave: Line voltage. Third wave: E_{TW} = e.m.f. induced in coil No. 9 at top of wedge.

seen from Table III the area enclosed by E_{TT} for the coil at the top of a tooth, is very much larger than E_{TW} for the coil at the top of a wedge. This can be explained on the assumption that a given peak is due to the change of the enclosed flux to nearly zero, from the value it had just before the coil left the

TABLE III.

Data relating to synchronous motor operation of machine and giving the area per one-half cycle per turn enclosed by the e.m.f. waves induced in coils No. 9 and No. 10.

No. of oscill.	Field amps.	Line amps.	Line volts	Power factor	Maxwells or volts per turn per ½ cycle
O A 29	6.4	39.5	237	0.45 ld.	45,000, coil No. 10
O A 29	6.4	39.5	237	0.45 ld.	12,036, coil No. 9
O A 27	4.24	15.5	218	1.00	59,400, coil No. 10
O A 27	4.24	15.5	218	1.00	29,800, coil No. 9

horn of the pole. This change will be much larger for a tooth than for a slot. The above, in connection with Tables II and III, give a fairly good idea of the flux distribution and flux pulsations under actual running conditions, in contrast to the phenomena which obtain with the machine stationary and which are easily investigated, as indicated in Fig. 9.

Study of Table II and the oscillograms given in connection therewith reveals several interesting facts. A comparison of Figs. 10 and 12 will show that the kinks between a + crest and a − crest, *i.e.*, under the pole-arc, are larger when the armature current is leading or demagnetizing than when it is lagging or magnetizing. Both E_{TT} and E_{TW} are larger for a given armature current when it is leading than when it is lagging; for example at 39.5 amperes of line current (under synchronous motor operation) $E_{TT} = 0.24$ and $E_{TW} = 0.12$ volts per turn. At 39.5 amperes of condensive current the volts per turn increase to 0.47 and 0.19 respectively. The field excitation in the former case was 2.9 amperes and the terminal voltage 212 (effective volts per phase); the corresponding quantities for the latter case being 6.4 amperes and 237 volts. In the light of the above, (see Table II) the explanation seems to be that in spite of the

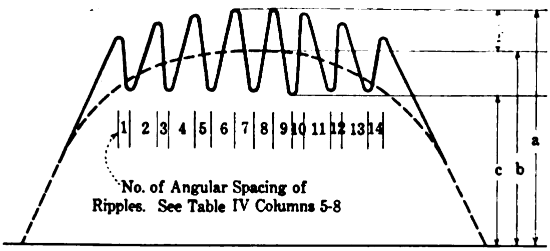


FIG. 13

Exaggerated figure showing c.m.f. induced in exploring coils at no-load and unequal spacing of tooth ripples.

demagnetizing action of the leading currents the flux density in the gap increases on account of the higher excitation and voltage.

Under s.s.c. the crest voltages E_{TT} and E_{TW} do not differ as widely which is no doubt due to the very peculiar and distorted flux distribution as will be explained in the next section.

In connection with the subject of tooth ripples, attention may be called to several other peculiarities. As seen from Table IV and indicated in Fig. 13, the angular spacing of the tooth ripples from crest to crest is not uniform as ordinary theory would indicate. (See equations **13** and **14**). In the first place, the angular spacing (1 + 2), (3 + 4), etc. Fig. 13, is slightly less than π/q, or in this case 15 electrical deg. Secondly the angular spaces 2, 4, 6, 11, and 13 are larger than 1, 3, 5, etc.; this is no doubt due to the hysteresis effect in the teeth. Thirdly, the amplitude d, Fig. 13 is distinctly smaller for E_{1T} than for E_{5B}

this is easily seen from Fig. 7 in which the waves were taken under the same operating conditions, using the same vibrator

TABLE IV.

Angular spacing in degrees (electrical) of the maximum and minimum crests of the tooth ripples of the no-load search coil e.m.fs.

No. of oscill.	Search coil	Field amperes	Mean angular spacing of (see Fig. 13)			
			1, 3, 5 & 7	2, 4 & 6	(1 + 2), (3 + 4), etc.	(2 + 3), (4 + 5), etc.
1	2	3	4	5	6	7
272	No. 1, top of slot	8.8	6	8.5		
O A 35	No. 1, top of slot		7.15	7.35	14.62	13.29
O A 35	No. 2, midd. of slot		6.46	7.81	13.9	14
O A 35	No. 5, bott. of slot		6.94	7.21	14	14.2
O A 38	No. 1, top of slot	5	6.64	7.45	14.18	14.4
O A 38	No. 3, midd. of slot	5	6.64	7.08	13.77	14
O A 38	No. 5, bott. of slot	5	6.84	8.03		
260	No. 1, top of slot	5	6.41	9.13		
263	No. 3, midd. of slot	4	6.03	8.43		
268	No. 5, bott. of slot	5	6.37	8		
Mean:			6.55	7.89	14.09	13.18

and the same vibrator resistance. A quantitative idea of the variations may be gained from Table V.

In Table VI are given the areas enclosed per ½ cycle by E_{1T},

TABLE V.

No. of oscillograms	E.m.f. of search coil	$\frac{d}{2} \times \frac{1}{b} \times 100$ See Fig. 13	Field amperes	Frequency cycles per second
272	E_{1T}	7.5%	8.8 appr.	50
272	E_{5B}	8.3%	8.8	50
O A 38	E_{1T}	7.2%	5	60
O A 38	E_{3M}	7.9%	5	60
O A 38	E_{5B}	9.2%	5	60

E_{3M} and E_{5B}, and it is seen that for the bottom coil No. 5 the flux is 107.5 per cent of that enclosed by the top coil. Under synchronous motor operation the percentage is smaller, about

103 per cent for leading, *i.e.* demagnetizing, and larger, about 113 per cent for lagging currents.

These phenomena may be explained on the basis of the following assumptions. Consider two surfaces, one passing through the top and the other through the bottom of the armature slots.

TABLE VI.

Mean areas of consecutive positive and negative half-waves of e.m.f. induced in full-pitch, 5 turn exploring coils at top, mddle, and bottom of slots = E_{1T}, E_{3M} and E_{5B} respectively.

No. of oscill. test No.	E_{1T} E_{3M} or E_{5B}	Frequency in cycles per sec.	Synchr. motor, short circuit or no load operation	Approx. power factor	Line current V	$(\theta_1-\theta_2)$ in mega-maxwells or volts per turn per cycle	$\theta_1-\theta_2$ in per cent	Field amps.
1	2	3	4	5	6	7 8	9	10
O A 32/104	E_{3M}	59.5	S. M.	0.42 ld.	45.2 ld.	2.31	100	
O A 32/104	E_{5B}	59.5	S. M.	0.42 ld	45.2 ld.	2.40	104	
O A 34/106	E_{1T}	59.5	S. M.	0.41 lg.	52.6 lg.	1.95	100	
O A 34/106	E_{3M}	59.5	S. M.	0.41 lg.	52.6 lg.	2.05	105	
O A 35/107	E_{1T}	59.5	S. M.	0.37 ld.	52.6 ld.	2.22	100	
O A 35/107	E_{3M}	59.5	S. M.	0.37 ld.	52.6 ld.	2.235	101.5	
O A 35/107	E_{5B}	59.5	S. M.	0.37 ld.	52.6 ld.	2.281	103	
O A 33/105	E_{1T}	59.5	S. M.	lag.	60 appro	1.93	100	
O A 35/105	E_{3M}	59.5	S. M.	lag.	60 appro	2.0	103.7	
O A 35/105	E_{5B}	59.5	S. M.	lag.	60 appro	2.18	113	
O A 38/110	E_{1T}	60	no load			2.316	100	5
O A 38/110	E_{3M}	60	no load			2.38	103.0	5
O A 44	E_{1T}	54	s.s.c. connection Y series			0.415	100	5
O A 72	E_{5B}	54	s.s.c. connection Y series			0.282	70.3	5
O A 51	E_{1T}	52	s.s.c. connection Y series			0.3095	100	3.16
O A 54	E_{3M}	52	s.s.c. connection Y series			0.245	79.2	3.16
O A 67	E_{5B}	52	s.s.c. connection Y series			0.0969	34.4	3.16
O A 81	E_{1T}	60	s.s.c. connection 2-phase			0.1348	100	4.96
O A 82	E_{5B}	60	s.s.c. connection 2-phase			0.1056	78.3	4.96

Assume that the flux density in the slots is smaller and in the teeth is larger and more nearly perpendicular[10] to the direction of rotation of the armature conductors, for the second surface than for the first. Further, if the armature were revolving, the

10. Compare equations (4) and (4a) in supplementary notes.

TABLE VII.

Order of harmonics	Wave analysis No.: (I − 2) No. of oscillogram: 206 Field current, amperes: 6.5 Frequency, cycles per sec.: 60 Exploring coil: No. 1, top of slot			(I − 4) 201 6 60 No. 1, top of slot			(I − 5) 206 5 60 No. 1, top of slot		
	A, volts B, volts	C, volts (C/C_1) 100	$\frac{A}{C_1} \times 100$ $\frac{B}{C_1} \times 100$	A, volts B, volts	C, volts $\left(\frac{C}{C_1} \times 100\right)$	$\frac{A}{C_1} \times 100$ $\frac{B}{C_1} \times 100$	A, volts B, volts	C, volts $\left(\frac{C}{C_1} \times 100\right)$	$\frac{A}{C_1} \times 100$ $\frac{B}{C_1} \times 100$
1	28.82	28.9	99.7%	27.93	27.99	99.85%	25.3	25.3	100%
	−0.62	100%	−2.14%	1.39	100%	4.97%	0.17	100%	0.66%
3	−0.73	1.08	−2.53%	−1.03	1.05	−3.68%	−0.88	0.95	−3.44%
	0.805	3.77%	2.78%	−0.21	3.75%	−0.75%	0.35	3.75%	1.36%
5	−2.22	2.24	−7.65%	−2.41	2.42	−8.61%	−2.18	2.19	−8.63%
	0.33	7.76%	1.12%	−0.24	8.65%	−0.86%	−0.14	8.65%	−0.56%
7	−2.28	2.28	−7.89%	−2.09	2.55	−0.75%	−2.02	2.05	−7.9%
	0.12	7.89%	0.403%	−1.47	0.91%	−5.26%	−0.33	8.09%	−1.3%
9	−0.81	0.94	−2.79%	0.02	0.09	0.07%	2.68	2.7	10.64%
	−0.48	3.25%	−1.67%	−0.09	0.03%	−0.03%	−0.00	10.65%	−0.02%
11	0.35	0.39	1.22%	0.14	0.64	0.05%	0.62	0.64	2.42%
	−0.17	1.35%	−0.58%	0.63	2.29%	2.25%	0.15	2.5%	0.59%
13	1.15	1.16	3.98%	0.44	0.72	1.57%	0.34	0.38	1.31%
	−0.15	4.02%	−0.52%	0.58	2.57%	2.07%	0.20	1.5%	0.78%
15	0.30	0.56	1.04%				0.13	0.26	0.50%
	0.47	1.93%	1.63%				0.22	1.02%	0.89%
17	−0.26	0.26	−0.88%				0.40	0.52	1.60%
	−0.03	0.9%	−0.12%				0.32	2.04%	1.26%
23	1.14	1.17	3.95%	−0.29	0.87	−1.04%	0.79	1.12	3.14%
	−0.27	4.05%	−0.9%	0.81	3.1%	2.93%	0.78	4.43%	3.09%
25	−0.87	0.88	−3%	0.49	1.09	1.75%	−0.65	0.77	−2.57%
	0.14	3.04%	4.95%	−0.97	3.89%	1.39%	−0.42	3.04%	−1.66%

Note: Wave analysis, I − etc. refers to open-circuit waves. First column gives the coefficients of the series: $A_1 \sin \theta + A_3 \sin 3\theta + \text{etc.} + B_1 \cos \theta + B_3 \cos 3\theta + \text{etc.}$ The second column gives the coefficients of the same wave when expressed as: $C_1 \sin \overline{\theta + \varphi_1} + C_3 \sin \overline{3\theta + 3\varphi_3} + \text{etc.}$ A, B and C are also given in per cent of C_1 in second and third columns.

TABLE VIII.

Wave analysis No.:	(I – 10)		(I – 13)		(I – 15)		(I – 21)		(I – 25)	
No. of oscillogram:	206		263		263		201		228	
Field amperes:	2.75		4		3		6		3	
Frequency:	60		60		60		60		60	
Exploring coil,	No. 1, top of slot		No. 3, middle of slot		No. 3, middle of slot		No. 5, bottom of slot		No. 5, bottom of slot	
Order of harmonics	*A*, volts / *B*, volts	*C*, volts / (C/C_1) 100	*A*, volts / *B*, volts	*C*, volts / $\frac{C}{C_1} \times 100$	*A*, volts / *B*, volts	*C*, volts / $\frac{C}{C_1} \times 100$	*A*, volts / *B*, volts	*C*, volts / $\frac{C}{C_1} \times 100$	*A*, volts / *B*, volts	*C*, volts / $\frac{C}{C_1} \times 100$
1	16.75	16.8	22.2	2.22	17.2	17.2	28.9	28.9	17.4	17.43
	0.97	100%	– 0.15	100%	0.05	100%	0.72	100%	0.002	100%
3	– 0.66	0.74	– 1.0	1.09	– 0.9	– 0.97	– 1.89	– 1.89	– 0.62	0.79
	0.35	4.4%	0.28	4.91%	0.36	5.64%	0.05	6.54%	0.5	4.55%
5	– 1.58	1.78	– 2.4	2.41	– 2.12	2.12	– 3.66	3.75	– 0.66	0.83
	– 0.8	10.59%	– 0.11	10.85%	– 0.14	1.23%	– 0.8	12.96%	– 0.5	4.76%
7	– 0.89	1.25	– 1.08	1.12	– 1.27	1.29	– 1.67	1.67	– 1.93	2.83
	– 0.88	7.44%	– 0.28	5.04%	– 0.26	7.50%	– 0.35	5.78%	– 2.07	16.23%
9	0.05	0.09	1.01	1.01	0.06	0.15	0.39	0.68	– 1.31	1.43
	– 0.08	0.56%	0.03	4.55%	– 0.13	8.55%	– 0.56	2.35%	– 0.58	8.20%
11	0.11	0.58	0.96	0.80	– 0.68	0.68	0.92	1.08	0.14	1.65
	0.57	3.45%	0.26	3.60%	0.097	3.95%	0.57	3.74%	1.64	9.47%
13	– 0.1	0.48					0.35	0.5		
	0.47	2.85%					0.36	1.73%		
15	0.75	0.17					– 0.24	0.26		
	– 0.16	1.01%					0.1	0.9%		
17	– 0.44	1.13					– 0.36	3.98		
	1.04	6.71%					– 3.96	13.76%		
23	– 0.34	– 0.34					0.67	1.02		
	– 0.00	2.02					1.77	3.53%		
25	0.47	0.47					– 0.72	1.25	0.48	0.55
	0.067	2.8					–1.02	4.33%	0.26%	3.17%

NOTE: Wave analysis *I* – etc. refers to open-circuit waves. First column gives the coefficients of the series: $A_1 \sin \theta + A_3 \sin 3\theta$ etc. $+ B_1 \cos \theta + B_3 \cos 3\theta$ etc. Second column gives coefficients of the same wave when transformed into: $C_1 \sin \overline{\theta + \varphi_1} + C_3 \sin \overline{3\theta + \varphi_3}$ etc. Coefficients *C* in per cent of fundamentals C_1 are also given in column (2).

peripheral velocity would have been larger for the second surface. These assumptions will partly at least explain the above and they seem reasonable as may be seen by examining the approximate flux distribution[11] in slotted armatures under different load conditions.

Tables VII and VIII give wave analysis of the e.m.fs. induced at no-load in different exploring coils. It will be seen that for a given field current, for example 6 amperes, wave analysis

TABLE IX.

Showing increase of 3rd harmonic of e.m.f. induced in stator exploring coils, with increasing excitation.

Excitation in amps. = I_f	Third harmonic e.m.fs. induced in stator full pitch exploring coils			Per cent values of columns				No. of oscillogram from which columns No. 2 | No. 3 | No. 4 were calculated		
	No. 1 E_{1T}	No. 3 E_{3M}	No. 5 E_{5B}	No. 1 I_f	No. 2 E_{1T}	No. 3 E_{3M}	No. 4 E_{5B}	No. 2	No. 3	No. 4
1	2	3	4	5	6	7	8	9	10	11
				No load operation						
8.8	2.21		3.94	320	298		532	272		272
6.5	1.08			236	146			206		
6.0	1.05		1.89	218	142		255	201		201
5.0	0.95	1.67	1.28	182	128	225	173	206	261	266
4.0		1.09		145.5		147			263	
3.0	0.75	0.97	0.79	109	101	131	107	228	263	228
2.75	0.74			100	100			206		
				Y series sustained short-circuit						
5	3.99		7.52	182	532		1000	202		286
4			5.12	145.5			684			286
3	2.46		4.04	109	328		538	229		286

NOTE: The sustained s.c. percentages are in terms of 0.75 volts, induced in top search coil No. 1 at no-load and 3 amperes excitation.

$I - 4$, the amplitudes in maximum volts for the 1st, 3rd and 5th harmonics are respectively, 27.99, 1.05 and 2.42 for coil No. 1. The corresponding values from wave analysis $I - 21$, Table VIII, for coil No. 5 at the bottom of the slot, are: 28.9, 1.89

11. See for example, Figs. 110 and 111 p. 282 and p. 283, Principles of Electrical Design, by A. Still. *Jour., I. E. E.*, Magnetic flux distribution in toothed core armatures. H. S. Hele-Shaw, A. Hay and P. H. Powell. Figs. 183, 223 etc. pp. 165 and 220, in S. P. Thompson's Polyphase Electric Currents, Second Edition.

and 3.75. As the third harmonic is of special interest in three-phase work Table IX has also been prepared; inspection of this table shows that taking the e.m.f. induced in coil No. 1, at the top of the slot, at 2.75 amperes of field excitation, as 100 per cent, the third harmonic of e.m.f. increases for coil No. 1 with increasing excitation until it reaches 298 per cent at 8.8 amperes of field current. Under s.s.c. we have a similar condition; the third harmonic for coil No. 5 reaches 1000 per cent while the corresponding value for coil No. 2 is 532 per cent at 5 amperes.[12]

In Fig. 14 the e.m.fs. E_{CTT} and E_{CTS} induced in a single

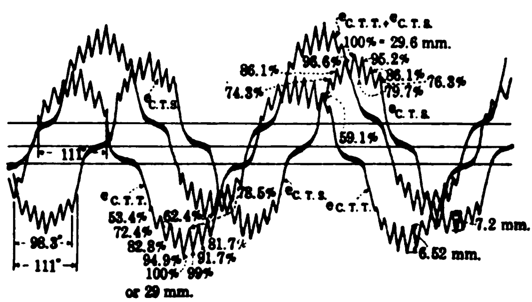


FIG. 14

Oscillogram No. O A 75. Test No. 187. Open-circuit test at 5 amperes field excitation and normal speed. First wave: (e.m.f. induced in single conductor No. 14 at top of tooth) + (e.m.f. induced in single conductor No. 13 at top of immediately succeeding wedge) = $E_{CCT} + E_{CTS}$. Second wave: E_{CTS}. Third wave: E_{CTT}. Same vibrator used for all exposures. 30 ohms resistance in vibrator for $E_{CTT} + E_{CTS}$; 10 ohms for other two waves.

conductor placed on top of a tooth and on top of a slot respectively (see coils No. 13 and 14, Fig. 3) show certain peculiar differences in that E_{CTT} has nine distinct kinks while E_{CTS} has eight. This is easily explained by following step by step the variational e.m.f. induced in a conductor on top of a tooth and one on top of a wedge, as the armature slots move with respect to the field poles.

12. For a tentative explanation of the fact observed, namely that the third harmonic of e.m.f. for a given exploring coil will increase with excitation see, P. Janet, *Lecons d' électrotechnique générale*, T. II, p. 191. However, note further that not only the 3rd harmonic increases for a given coil with increase of field current but it seems to increase faster for a search coil at the bottom of slot than one at the top of a slot.

IV. Experimental Investigation of the Direct Component of Armature Reaction and the Resultant Flux Distribution Under Sustained Short Circuit Conditions

The armature current under s.s.c. has been found to be very closely sinusoidal, as can be seen by inspecting first two waves in Fig. 15 and fifth wave in Fig. 16, which are for Y and delta

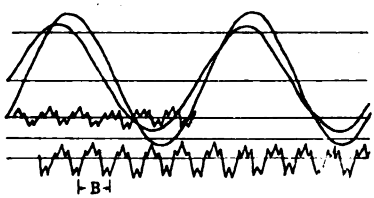


Fig. 15

Oscillogram No. 281. Table X. Sustained short circuit with machine series delta connected. Second straight line; zero line for first two waves representing armature phase current at 3.27 and 4.1 amperes field excitation respectively. Third and fourth waves give e.m.f. induced in 29-turn full-pitch rotor exploring coil No. 7, under same conditions.

connections. A quantitative idea of the approach of these waves to a sine wave may be gained from Table X.

Throughout this paper the armature current under s.s.c. will be assumed to be sinusoidal and if the armature winding were

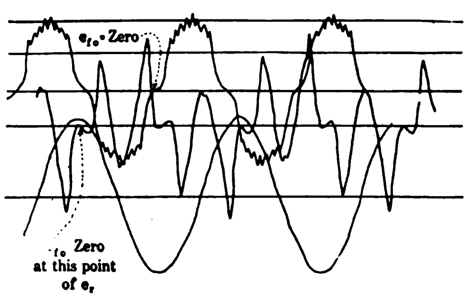


Fig. 16

Oscillogram No. O A 44. Test No. 148, Table XV. *Exposure No.* 1. Open-circuit test at 5 amperes field excitation and 54 cycles per second. First wave: contactor. Third wave: E_{1T} = e.m.f. induced in coil No. 1. *Exposure No.* 2. Sustained short-circuit test with machine series Y connected. Same excitation and speed as before. Fourth wave: E_{1T}. Fifth wave: line current. Second wave: contactor.

sinusoidally distributed, see Fig. 17, the armature m.m.f. would be sinusoidal. However, it can be shown (see supplementary notes, equation **30**) than an ordinary armature winding with N conductors per slot and one slot per pole per phase, see Fig.

18, supplied with a sinusoidal current will be exactly equivalent to: (1) a winding sinusoidally distributed (in space) having a pitch of τ cm. or inches. (2) a winding sinusoidally distributed having a pitch of $\tau/3$ and ⅓ as many turns as the first, etc., etc. In other words, imagine a set of sinusoidally distributed windings, of pitch τ/k, where k is the order of the space harmonic,

TABLE X.

Per cent amplitude of armature current, i_a, at every 30 deg., under s.s.c. and the machine Y-series and delta-series connected.

θ in degrees	0	30	60	90	120	150	180
$\sin\theta \times 100$	0	50	86.6	100	86.6	50	0
i_a, Y conn. (oscill. O A 44)	0	51.1	84.5	100	85.4	50	0
i_a, Δ conn. (oscill.281)	0	48.7	81.2	100	85.1	48.7	0

all placed in series and carrying the same sinusoidal current (with respect to time): These will produce the same H-curve as the actual non-sinusoidal winding carrying the sine-wave current of fundamental (with respect to time) frequency.

Without going further into the analysis of this, suffice to

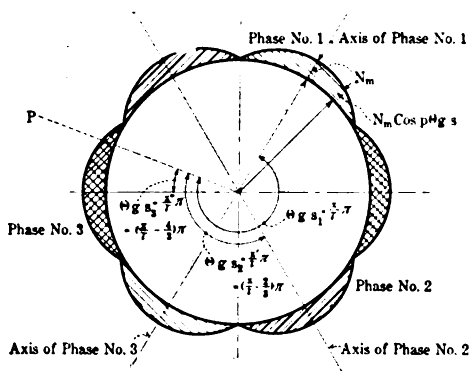


FIG. 17

Schematic representation of three-phase two-pole armature winding which is sinusoidally distributed (in space).

state[13] that for a polyphase alternator, with a sine wave (with respect to time) armature current and any ordinary type (non-

13. See A. Potier, *Journal de Physique*, 1897, 3^{me} serie, T. VI, p.341 and 483. A. Blondel, *L' Eclairage Electrique*, 1895, T. IV, pp. 241, 308 et 358. T. V., p. 268. See also P. Janet, *Lecons d' Electrotechnique générale*, T. III, Chp. V. Alex. Russell, Altern. Currents Vol. II, Chp. XIV.

sinusoidally distributed, in space) winding, the resultant m.m.f. curve can be considered as consisting of a series of H-curves, all of fundamental frequency (in time) but having a pole pitch τ/k and an amplitude equal to:

$$H_a = \frac{N_{ph}}{2} \cdot \frac{H_m}{k} S \cdot D_f \cdot S_{p.f.} \tag{31}$$

where N_{ph} = number of phases.
H_m = $(4/\pi)\ Y_m$. See Fig. 18.
S = slots per pole per phase.

D_f = distribution factor = $\dfrac{\sin \frac{1}{2} S \frac{\lambda}{\tau} \pi}{S \sin \frac{1}{2} \cdot \frac{\lambda}{\tau} \pi}$

λ = slot pitch.
$S_{p.f.}$ = short-pitch factor = $\cos \epsilon k \pi$, where $(1 - \epsilon)\tau$ = winding pitch.

For a three-phase alternator the first, seventh, thirteenth etc., or $(6n + 1)\ th$ space harmonics, (n = 0, 1, 2, 3 etc.), will rotate in the same direction at a speed of $2\pi f/k$ or at an angular velocity $\omega/p\,k$. The $(6n - 1)\ th$ harmonics will rotate in the opposite direction with the same velocity. In mathematical short-hand the above may be expressed as follows:

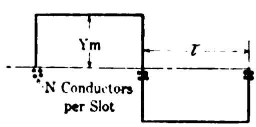


FIG. 18

$$H_1 = H_a \cos\left(\omega t - \frac{x}{\tau}\pi\right) \tag{32}$$

$$H_3 = 0 \tag{33}$$

$$H_5 = H_a \cos\left(\omega t + \frac{5x}{\tau}\pi\right) \tag{34}$$

$$H_7 = H_a \cos\left(\omega t - \frac{7x}{\tau}\pi\right), \text{ etc.} \tag{35}$$

where H_a is given by (**31**).

In case of two-phase machines the first, fifth etc., or $(4n + 1)\ th$ space harmonics will travel in one direction while the third, seventh etc. or $(4n - 1)\ th$ space harmonics will travel in the opposite direction. The expressions for these will be similar to the ones given above and their amplitude will be given by (**31**)

The m.m.f. per centimeter at any point x of the stator periphery will be ($4\,\pi .\ 10^{-1}\,H$) where,

$H = H_1 + H_5 + H_7$ etc.

= sum of series of sinusoidal H-waves, all of fundamental frequency and having phase angles, $(-\,6\,x_1\,\pi/\tau)$, $(+\,6\,x_1\,\pi/\tau)$, $(-\,12\,x_1\,\pi/\tau)$, etc., with respect to the fundamental whose phase angle $(-\,x_1\,\pi/\tau)$ is assumed to be zero. See Notes B and C.

This leads to the following important proposition: With polyphase balanced alternating currents varying according to a sine law (in time) and flowing through ordinary non-sinusoidally distributed windings, (in space) the H-curve will be sinusoidal (*i.e.*, will be the sum of a series of sine waves). Thus, under load

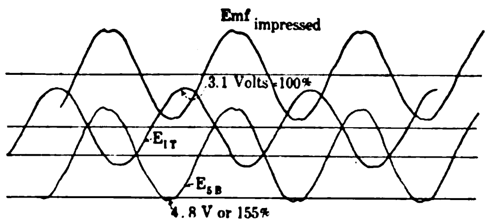


FIG. 19

Oscillogram No. O A 13. Test No. 32. Rotor removed and three-phase 85.8 amperes (158 per cent normal current) introduced into the stator from outside source. First wave: e.m.f. impressed on stator. Second wave: E_{1T} = induced in full pitch search coil No. 1 Third wave: E_{5B} = e.m.f. induced in full pitch exploring coil No. 5. Second and fifth lines: calibrations for E_{1T} and E_{5B} respectively. Note E_{1T} and E_{5B} set up by three-phase currents.

or s.s.c., in case of induction motors or alternators, the H-curve due to sinusoidal (in time) armature currents will be sinusoidal. Consequently if the permeability be constant, and uniform across the pole-face, the B-curve due to armature reaction will also be sinusoidal. However, if we find the e.m.fs. induced in exploring coils due to armature reaction to be distorted this must be charged to the permeability μ, of the circuit. The importance of this result will be appreciated when we attempt to explain certain phenomena to be considered presently.

Fig. 19 gives E_{1T} and E_{5B} when the stator was supplied with 3-phase currents from an outside source and the rotor removed. It is seen that the impressed e.m.f. does not deviate greatly from a sine wave. But the e.m.f. E_{5B}, induced in the coil at the bottom of the slot is peaked and over 150 per cent of E_{1T} = e.m.f. induced in coil on top of slot. The waves given in

Fig. 20 were taken with the rotor in place and running without excitation at a speed corresponding exactly to that of the gliding field produced by the three-phase stator currents. In this case the current supplied was only 28 per cent of full-load current. As in Fig. 19, E_{5B} is more peaked than E_{1T}; $E_{5B} = 1.17\ E_{1T}$.

Assuming the m.m.f. per centimeter to be the same at the top and bottom of the slot, it is clear that the inequality between E_{1T} and E_{5B} must be charged, at least partly, to the difference in permeance between the points considered. Generalizing the above it can be stated that although the H-curve due to armature currents may be sinusoidal the B-curve will differ from the former for two reasons: First, the lack of constancy and uniformity in μ across the pole face; further the B-curve at the bottom of the slot may differ from that at the top owing to the difference in the permeance per unit area at these two points.

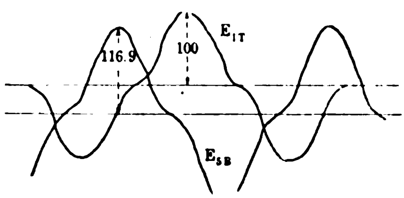


FIG. 20

Oscillogram O A 66. Test 177. First wave: E_{1T} = e.m.f. induced in full-pitch search coil at top of slot. Second wave: E_{5B} = e.m.f. induced in full-pitch search coil at bottom of slot. A-c. supplied from outside source = 15.1 amperes. Two exposures taken under identical conditions. Rotor not excited and run at synchronous speed. Same vibrator used for both exposures.

Second, according to the degree of saturation the B-curve will be more or less flat topped; this of course is well known especially in connection with induction motor design.

It is possible for the B-curve due to armature reaction alone, to undergo certain oscillations, similar to those described in Section III. However, a little study of Table I, columns 8 and 9 and of Figs. 19, 20 and of others to be given later will show that these secondary effects may safely be neglected.

The experimental and theoretical studies given herein and by others show that the no-load flux may and does deviate from a sine wave to the extent of containing the 3rd, 5th and 7th harmonics to the amount of 10 per cent or thereabouts. The field-form of most modern machines, at no-load or full-load approaches reasonably well the general shape of a sine wave[14]

14. W. J. Foster, TRANS., A. I. E. E., 1913, Vol. 32, p. 749. L. A. Herdt, TRANS., A. I. E. E., 1902, Vol. 19, p. 1093.

and is symmetrical with respect to the $\pi/2$ or the (geometrical) pole-axis except in case of loads having considerable cross-magnetizing effect.

As explained before the H-curve due to armature reaction will be sinusoidal while the B-curve will show no *extreme* deviations from a sine wave. This, rather theoretical result, is

TABLE XI

Wave analysis No.:	*II* − 1		*II* − 2		*II* − 3		*II* − 4	
No. of oscillogram:	202		229		286		286	
Field excit. amperes:	4.95		3		5.02		3	
Expl. coil,	No. 1, top of slot		No. 1, top of slot		No. 5, bottom of slot		No. 5, bottom of slot	
Order of harmonics	A, volts / B, volts	C, volts / $\frac{C}{C_1} \times 100$	A, volts / B, volts	C, volts / $\left(\frac{C}{C_1}\right) 100$	A, volts / B, volts	C, volts / $\left(\frac{C}{C_1}\right) 100$	A, volts / B, volts	C, volts / $\left(\frac{C}{C_1}\right) 100$
1	1.24	1.24	1.16	1.16	− 1.05	1.39	0.85	0.86
	− 0.004	100%	− 0.03	100%	− 0.92	100%	0.13	100%
3	1.96	3.99	0.98	2.46	− 3.64	7.42	1.97	4.24
	3.32	323%	2.26	213%	− 6.47	532%	3.74	490.5%
5	1.06	2.14	0.17	1.77	1.77	2.24	− 1.15	1.49
	− 1.86	172.5%	− 1.16	152.5%	− 1.37	160.5%	− 0.96	173%
7	0.91	1.45	0.67	1.1	− 1.05	2.7	1.25	2.04
	− 1.12	116.8%	− 0.78	95%	− 2.47	193%	− 1.61	236%
9	0.45	0.45	0.03	0.03	− 1.18	1.38	1.51	1.75
	0.027	36.5%	− 0.001	2.8%	0.72	98.9%	0.87	203%
11	− 0.31	0.32	− 0.24	0.03	− 0.11	0.11	− 0.18	0.38
	− 0.097	25.86%	− 0.01	2.24%	− 0.02	81%	− 0.34	44.4%
13	− 0.193	0.39	− 0.01	0.27	− 0.88	1.29	− 0.33	0.71
	− 0.34	31.7%	− 0.02	2.29%	0.95	92%	0.63	82.5%
15	0.128	0.15	0.004	0.004				
	0.086	12.5%	0.003	0.4%				
17	− 0.056	0.12						
	0.10	9.5%						
23	0.005	0.12						
	0.12	9.5%						
25	0.004	0.006						
	0.004	0.5%						

NOTE: Wave analysis, II-etc. refers to analysis of waves obtained under s.c.c. with the machine series Y connected. See also note, Table VIII, as to meaning of A, B, C.

further corroborated by the oscillograms given in Figs. 19 and 20. According to these, either with the rotor removed or in place and running at synchronous speed, the e.m.fs. induced in stator search coils, due to stator currents alone, are fairly smooth. Furthermore the flux pulsations as indicated by the rotor coil e.m.fs., E_{RF}, and E_{RC} (under s.s.c.) were found to be extremely small.

The resultant of two or more sine waves is, of course, a sine wave, and therefore it might be expected, at first sight, that the resultant of the B-curve due to the field and that due to the armature reaction will not deviate greatly from a sine wave, since neither of them is very distorted to begin with. However, turning to oscillograms obtained under s.s.c. we find indications of an extremely distorted flux distribution. A glance at Figs. 23, (fourth wave) 16, (fourth wave) etc. and Table XI which gives the coefficients of the harmonics of the waves obtained under s.s.c., show that the 3rd harmonic of e.m.f. induced in the stator search coils is several hundred per cent of the fundamental and that a number of other harmonics are quite comparable to it.

In order to avoid any false deductions and detect any peculiar defects in the machine under test to which the distorted s.s.c. waves might be due it was considered advisable to investigate

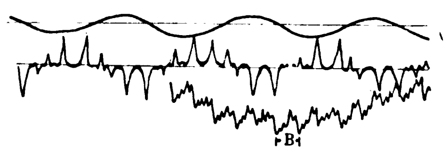


FIG. 21

Oscillogram No. O A 40. Test No. 116. Tables I and II. First wave: line current Second wave: E_{TT_2} = e.m.f. induced in coil No. 12. Third wave: E_{RF} = e.m.f induced in full-pitch rotor coil No. 7. Synchronous motor operation. Line current = 76 amperes lead. Line voltage = 241 volts. Power factor = 0.28 ld.

briefly the B-curves obtained under different loads. For this purpose the machine was run as a synchronous motor and a number of oscillograms taken, a few of which have been included in the paper.

As seen from Figs. 21, 22 etc., the waves E_{1T} E_{3M}, E_{RF}, E_{RC} etc. are not unlike those obtained at no-load with small variations which might have been expected. It will be observed by comparing Fig. 22 and Fig. 7 that the tooth ripples are smaller under synchronous motor operation. One of the important results of this series of tests was that even with heavy magnetizing or demagnetizing armature reactions, (no field excitation, or 150 per cent or more excitation) the flux distribution did not in any way approach the B-curves obtained under s.s.c.

Other points of interest have already been considered in the previous section and as the subject is not new it will not be

considered any further. However, attention may be called to the e.m.f. induced in the rotor search coils No. 7 and 8. The e.m.f. waves of these coils show $2q = 24$ small indentations per cycle which are due to the teeth. The e.m.f. of full-pitch coil No. 7, shows a large superimposed oscillation which recurs every B deg., see Fig. 21, 3rd wave.

As shown clearly in the supplementary notes this is due to the fifth and seventh space harmonics of armature reaction and as indicated in Table I column 5, $B = 60$ elec. deg., Fig. 21, *i.e.*, the periodicity of the superimposed wave is $360/60 = 6$ times machine-frequency, as we would expect. The long flat oscillations which repeat themselves every $A = 1080$ elec. deg., see Fig. 5, and Table I column 4, are due to eccentric rotor, as explained before.

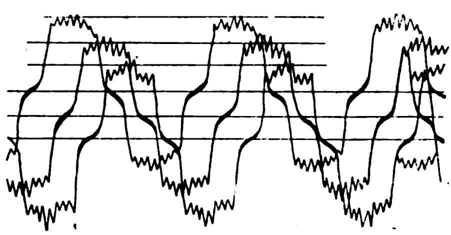


FIG. 22

Oscillogram No. O A 35. Test No. 106. Table VI. Machine Y parallel connected and run as synchronous motor. First wave: E_{1T} = e.m.f. induced in exploring coil No. 1 at top of slot. Second wave: E_{3M} = e.m.f. induced in exploring coil No. 3 at middle of slot. Third wave: E_{5B} = e.m.f. induced in exploring coil No. 5 at bottom of slot. Line current = 52.6 lead. Power factor = 0.37 approx.

To determine the armature reaction under s.s.c., *experimentally,* in terms of the voltages induced in the stator coils the writer resorted to the following method. A contactor[15] having a fixed space relation with respect to the poles was placed on the machine. This closed a direct-current circuit of very little inductance so that the rise of current was quite abrupt and the instant of make well defined. See Fig. 23. An exposure was first made giving the contactor wave and the open circuit e.m.f. induced in one of the search coils. The zero lines of both waves were then moved, in the same direction, and a second exposure was made giving the contactor and search coil e.m.f. under the same operating conditions except that the machine was short-circuited at its terminals.

15. The contactor used is similar to the one described in TRANS., A. I. E. E., Vol. 34, p. 2254, except for slight changes in the design of the brush rigging.

Obviously it is thus possible to determine accurately the point on the s.s.c. wave corresponding to any point on the open-circuit wave. If we designate by e_{fo} the e.m.f. induced in one of the stator coils No. 1, 3, or 5 at no-load and given field current

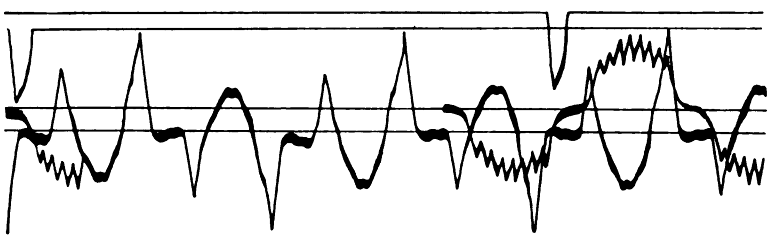


Fig. 23

Oscillogram No. O A 72. Test No. 184. Table XV. *Exposure No.* 1. Open-circuit run at 5 amperes field current and 54 cycles per second. First wave: contactor. Third wave: E_{5B} = e.m.f. induced in exploring coil No. 5, at bottom of slot. *Exposure No.* 2 Sustained short circuit; series Y connection and under same conditions. Second wave Contactor. Fourth wave: E_{5B}.

and speed, and by e_r the e.m.f. induced in the same coil under the same conditions of speed and excitation but with the machine short-circuited, we can, as a fair approximation assume that e_{fo}

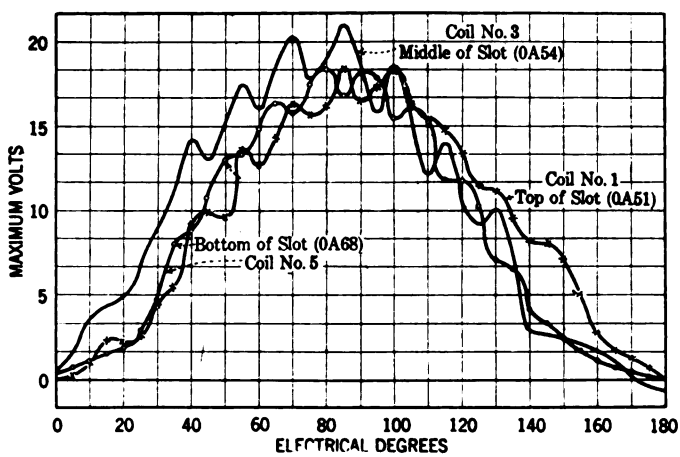


Fig. 24

E_a curves = difference between no-load and s.s.c./e.m.fs. induced in top, bottom and middle of slot full-pitch exploring coils, Nos. 1, 3 and 5 = $(E_{fo} - E_t)$—field current = 3.16 amperes — periodicity = 52 cycles per second — Y series connection.

plus a certain e.m.f. e_a, which we can charge to armature reaction, give us the resultant e.m.f. e_r.

Fig. 24 shows $e_a = (e_r - e_{fo})$ for the three full-pitch stator exploring coils taken at a field excitation of 3.16 amperes and a

TABLE XII.

	Wave analysis: VI – 1 No. of oscillogram: O A 44 Field excitation: 5 Frequency: 54 Exploring coil: No. 1, top of slot			(VI – 2) O A 51 3.16 52 No. 1, top of slot			(VI – 3) O A 68 3.1 52 No. 5, bottom of slot		
Order of harmonics	A, volts B, volts	(A/C_1) 100 (B/C_1) 100	C, volts (C/C_1) 100	A, volts B, volts	(A/C_1) 100 (B/C_1) 100	C, volts (C/C_1) 100	A, volts B, volts	(A/C_1) 100 (B/C_1) 100	C, volts (C/C_1) 100
1	– 23.02	– 99.8%	23.07	– 15.22	– 99.4%	15.31	14.75	100%	14.75
	1.16	5.03%	100%	1.64	10.73%	100%	0.2	1.35%	100%
3	4.87	21.0%	5.06	2.09	13.62%	2.14	0.85	5.76%	0.92
	– 1.38	– 6.01%	21.05%	– 0.65	– 4 27%	14%	0.35	2.37%	6.24%
5	– 0.87	– 3.77%	0.9	0.73			– 0.6	– 4.1%	0.62
	– 0.25	– 1.10%	3.93%	– 0.34			– 0.12	– 0.8%	4.18%
7	0.56	2.44%	0.68	– 0.08			0.22	1.47%	0.35
	0.38	1.67%	2.94%	– 0.52			0.27	1.8%	2.35%

Note: Wave analysis VI – etc. refers to C_a curves of armature reaction See Figs. 25 and 24. First column gives coefficients of series; $A_1 \sin \theta + A_3 \sin 3\theta$ etc. $+ B_3 \cos \theta + B \cos 3\theta$ etc. Second column gives A and B in per cent of C_1. Third column gives coefficients of series $C_1 \sin \overline{\theta + \varphi_1} + C_3 \sin \overline{3\theta + \varphi_3}$ etc. where $C^2 = A^2 + B^2$; also it gives C in per cent of C_1

frequency of 52 cycles per second; 3.16 amperes being the field excitation necessary to send full-load current under s.s.c. Fig. 25 gives e_a for a frequency of 54 cycles per second and a field current of five amperes.

Table XII gives the wave analysis of e_a, Fig. 25 coil No. 1, and Fig. 24 coils No. 1 and 5. It is seen that the 3rd harmonic is 21 per cent for five amperes field excitation and drops to about 5 and 6 per cent at 3.1 amperes of excitation. A general idea of the shape of these e_a curves of armature reaction may be obtained from Fig. 24A which is an average "smoothed out" curve representing the waves given in Fig. 24 for coils No. 1 and 5.

The last two columns of Table XIII give the wave analysis of

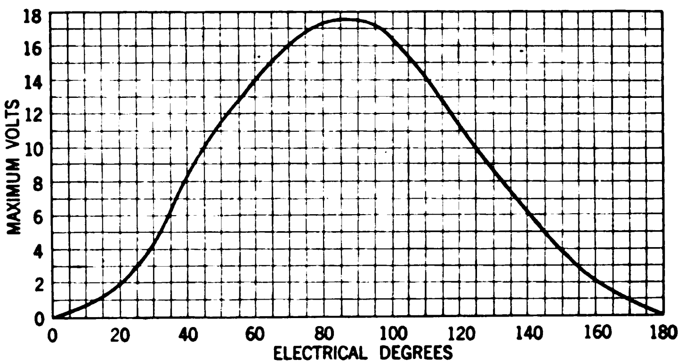


FIG. 24A

Average "Smoothed Out" curve representing e.m.f., E_J induced in coils No. 1 and No. 5 Fig. 24.

e_a as obtained by subtracting (1 – 5) Table IV, from (*II* – 1) Table XI. (*I* – 5) gives the wave analysis of the e.m.f. induced in coil No. 1 at no-load and 5 amperes of excitation, while (*II* – 1) gives the analysis of the corresponding wave of the same coil with the machine Y connected and short-circuited. Comparing (*II* – 1) – (*I* – 5) with the wave analysis of e_a, Table XII, it will be seen that the agreement is satisfactory.

The important result derived from the above is that the s.s.c. flux distribution is badly distorted primarily on account of the fact that the fundamental of the resultant flux is so greatly reduced that the higher harmonics become quite predominant. For example, from Table VII, wave analysis (*I*–5), the 3rd is seen to be 0.95 volts which is 3.75 per cent of the no-load fundamental, which is 25.3 volts; but it is $(0.95/1.24) \times 100 = 67$ per cent

TABLE XIII.

	Wave analysis No. III – 2 No. of oscillogram: 225 Field excitation amperes: 5.05 Exploring coil, No. 1, top of slot		(III – 4) 227 3 No. 1, top of slot		(V – 4) O A 81 5 No. 1, top of slot		(V – 5) O A 82 5 No. 5, bottom of slot		(II – 1) – (I – 5) 5 No. 1, top of slot	
Order of harmonic	*A*, volts *B*, volts	*C*, volts (C/C_1) 100	*A*, volts *B*, volts	*C* volts (C/C_1) 100	*A*, volts *B*, volts	*C*, volts (C/C_1) 100	*A*, volts *B*, volts	*C*, volts (C/C_1) 100	*A*, volts *B*, volts	$A/25.3$ 100 $(B/25.3)$ 100
1	– 0.75	1.21	0.525	1.00	– 2.65	2.65	– 2.19	2.64	– 24.06	95.2
	0.96	100%	0.86	100%	0.05	100%	1.48	100%	– 0.18	0.71
3	1.74	3.54	1.17	2.13	– 3.77	3.78	– 4.9	4.96	2.84	– 11.21
	3.09	291.5%	1.78	213%	0.28	144%	0.82	188	2.97	– 11.74
5	– 1.4	1.76	– 0.94	1.0	1.93	1.99	1.6	2.15	3.24	– 12.8
	– 1.07	144.8%	0.38	100%	– 0.47	75%	– 1.44	81.5	– 1.72	6.8
7	0.97	0.99	0.38	0.64	1.22	1.375	1.29	1.9	2.93	– 11.58
	– 0.20	81.6%	0.51	63.7%	– 0.63	51.8	– 1.4	71.9	– 0.79	3.12
9	0.89	0.94	0.19	0.39					– 2.23	8.82
	– 0.28	77.1%	– 0.35	39.3%					0.03	
11	– 0.47	0.94	0.048	0.99					– 0.93	3.7
	0.82	77.4%	– 0.08	9.57%					– 0.25	0.99
13	– 0.25	0.40	0.15	0.32					– 0.53	2
	– 0.31	33.1%	– 0.28	0.32%					– 0.54	2.13
15	0.25	0.29							0	
	0.01	23.8%							– 0.31	1.23
17			0.07	0.25					– 0.46	1.82
			– 0.24	25.1%					– 0.22	0.87

NOTE: Wave analysis III etc. refers to analysis of waves obtained under s.s.c. with the machine series Y connected and neutral in. V etc. refers to waves obtained under s.s.c. with the machine connected two-phase. See Fig. 31. For II – 1 see Table XI; for I – 5 see Table VII. As to meaning of *A*, *B* and *C* see Table XII.

of the s.s.c. fundamental. From wave analysis ($II - 1$) Table XI, the third harmonic under s.s.c. is 3.99 volts *i.e.*, (3.99/25.3) $\times$ 100 = 16 per cent of the no-load fundamental, but (3.94/1.24) $\times$ 100 = 323 per cent of the s.s.c. fundamental. The increase from 0.95 volts to 3.99, on the other hand, must be charged mainly to the B-curve of armature reaction which will be distorted, unlike the H-curve producing it, which will be sinusoidal

Turning to Table XII, consider wave analysis No. ($VI - 1$) which gives the coefficients for E_{1T} at five amperes excitation and 54 cycles per second. The fundamental is seen to be 23

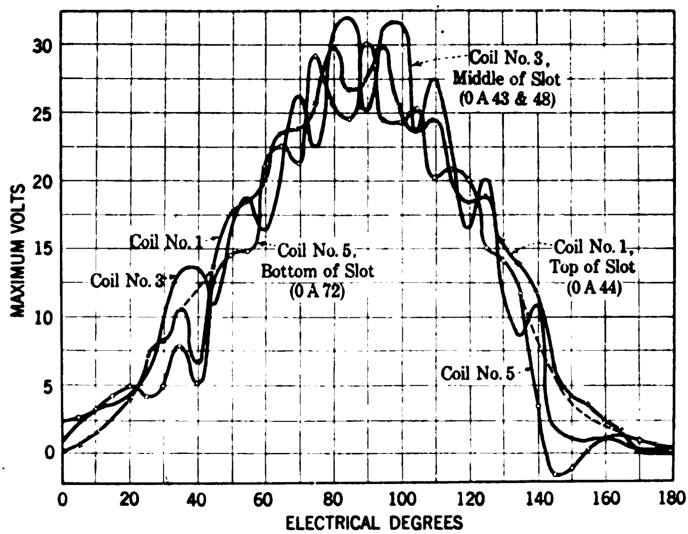


FIG. 25

E_a curves = $E_{fo} - E_r$ = difference between open-circuit and s.s.c. e.m.fs. induced in full-pitch exploring coils Nos. 1, 3 and 5 — field current = 5 amperes—periodicity = 54 cycles per second—Y series connection.

volts; the 3rd is 21 per cent of e_a but (60/54) (5.05/1.24) $\times$100 equals 450 per cent of the s.s.c. fundamental.

In general, then, if both the flux distribution at no-load and the flux wave due to armature reaction are distorted to the extent of containing 10 to 20 per cent 3rd and 5th harmonics, the resultant s.s.c. flux distortion will be badly distorted, because the above harmonics will amount to several hundred per cent of the fundamental, of the s.s.c. wave. Assume, for example, that e_{fo} and e_a consist of:

	e_{fo}	e_a
1st harmonic	100 per cent	− 95 per cent
3rd "	10 " "	10 " "
5th "	5 " "	5 " "

These values are quite conservative as inspection of Tables VII, VIII, and XII will show, and neither of the waves can be said to be very distorted. The resultant s.s.c. flux distribution will be equal to $e_r = (e_{fo} + e_a)$ and the amplitudes of its 1st, 3rd, and 5th harmonics will be 5, 20 and 10 or 100, 400 and 200 per cent respectively, in terms of the s.s.c. fundamental. These

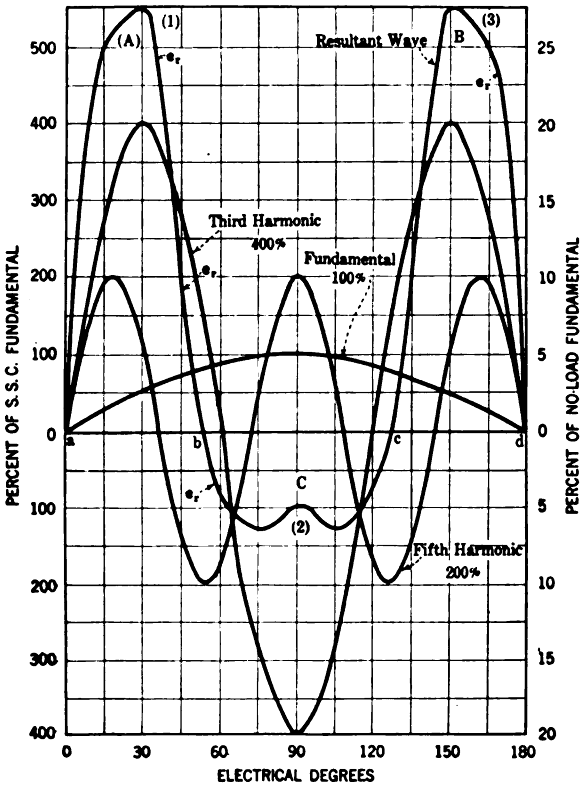


FIG. 26

Illustrating how the extremely distorted resultant wave forms are produced under sustained short circuit.

are drawn in Fig. 26 and their sum, e_r is seen to be extremely distorted and not unlike the waves obtained experimentally under s.s.c.

It is clear now why the flux distribution waves under synchronous motor operation deviate comparatively little from the no-load curve. Obviously at very low voltages such as are obtained under s.s.c., the harmonics of the field and armature reaction

will assume a predominant rôle (unless they happen to be out of phase by ½ of their own period and thus neutralize each other).

In Fig. 27 the angular spacings between different crests are

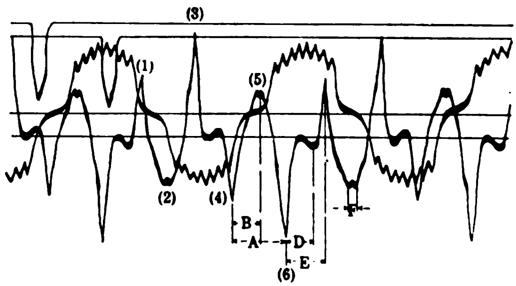


FIG. 27

Oscillogram No. O A 68. *Exposure No.* 1. First wave: contactor. Third wave e.m.f. induced in coil No. 5 at no-load, 3.1 amperes field excitation, 52 cycles per second. *Exposure No.* 2: Machine series Y connected and short-circuited at same excitation and speed. Second wave: contactor. Fourth wave: E_{5B}. See Fig. 24.

designated, A, B, D, E and F and their values for different kinds of s.s.c. are given in Table XIV. From this it is seen that A is approximately 105 deg., or nearly equal to the pole-arc, as it would be expected—see Fig. 26; E, Fig. 27, is about 75 deg.

TABLE XIV.

Data relating to the e.m.fs. induced in the coils at the top and bottom of different slots under s.s.c. and the machine connected, series Y, series △ and two phase. Frequency = 60 cycles per second.

No. of oscill.	Field amps.	E_{1T} E_{6B}	Kinds of short-circuit	A	B	D	E	F
				in degrees see Figs. 27, 34, etc.				
202	4.95	E_{1T}	Y	105	51.3	40	75.5	19
O A 88	5	E_{1T}	Y	106.3	48	35.6	65.2	10
226	5	E_{1T}	Y neutral in	109	51	37	70	
O A 89	5	E_{6B}	Y	103.2	50.4	37.1	73.6	10
O A 88	5	E_{1T}	△	104.5	49.7	41.8	75.4	10
275	4.9	E_{6B}	△	106.2	50.8	39 2	73.5	
O A 89	5	E_{6B}	△	104.5	49.3	36.8	72.0	
O A 81	4.96	E_{1T}	two-phase	105	51.1	36.8	72.3	17.4
O A 86	4.96	E_{1T}	two-phase	105.3	47.8	48.2	76.1	15
O A 82	4.96	E_{6B}	two-phase	104.9	52.4	42.9	79.2	10.1

so that $(A + E) = 180$ deg. D is nearly $(1/2\,E)$ but B is less than $(1/2\,A)$; referring to the theoretical assumed curve e_r of Fig. 26, it will be easily seen that if the transverse armature reaction (due to the active or in-phase component of armature

current with respect to the geometrical pole-axis) is not entirely negligible, the peaks (1) and (3) will be unequal, as it is the case in actual oscillograms Figs. 23 and 27, etc. A little consideration will show that the cross-magnetizing armature reaction

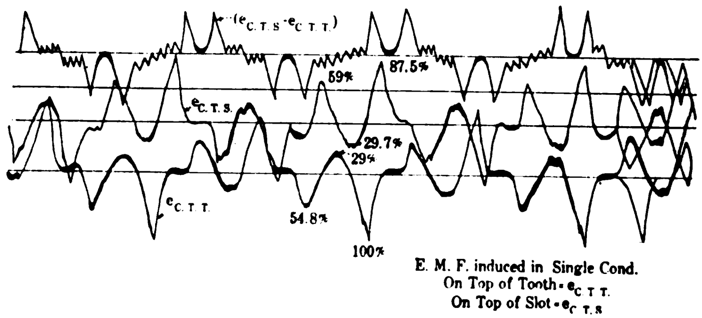


FIG. 27A

Oscillogram No. O A 76. Test No. 188. *Exposure No.* 1. Open circuit run at 5 amperes field excitation and normal speed. First wave = $(E_{CTT} - E_{CTS})$ = (e.m.f. induced in single conductor at center of tooth, No. 14, Fig. 3) – (e.m.f. induced in single conductor at top of succeeding wedge, No. 13, Fig. 3). This should be compared with Fig. 14. *Exposure No.* 2. s.s.c. run under same conditions. Second wave: E_{CTS}. Third wave: E_{CTT}. These two waves should be compared with Figs. 23, 27, 28a, etc., which give the e.m.fs. induced in full-pitch exploring coils.

will not only reduce, say crest (3), Fig. 26, but will shift crest (2) towards (3). Thus the angle B, between (2) and (3), Fig. 26, will be less than $(1/2\,A)$ = angle between crests (1) and (3), Fig. 27.

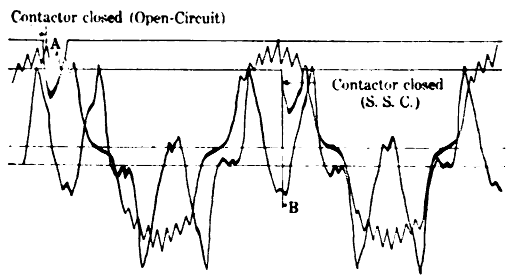


FIG. 28

Oscillogram No. O A 81. Test No. 193. Tables XIV and XV. First wave: Contactor Third wave: E_{1T} = e.m.f. of coil No. 1 at 4.96 amperes of field current, 60 cycles per second and no-load. Second wave: contactor. Fourth wave: E_{1T} under same conditions except machine short-circuited and connected two-phase.

In Fig. 27 the different crests are designated 1, 2, 3, etc. and their values in maximum volts for different kinds of s.s.c. are given in Table XV. Study of this table shows that for three-phase Y or delta s.s.c. the peaks on the same side of the zero line,

i.e., (1), (3) or (4), (6) are quite unequal which might have been expected according to the preceding paragraph. Compare also Fig. 27A. In case of two-phase s.s.c., however, the corresponding crests (1), (3) or (4), (6) are very nearly equal. See Fig. 28.

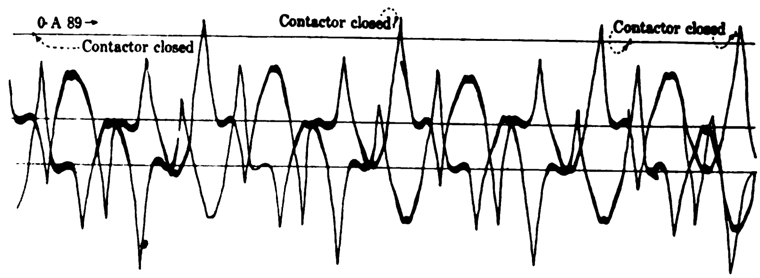
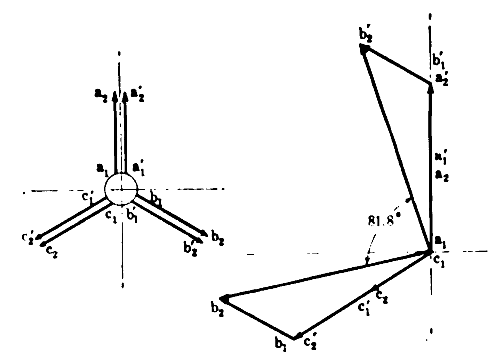


FIG. 28A

Oscillogram No. O A 89. Test No. 201. Table XIV and XV. First wave: Contactor. Third wave: E_{5B} = e.m.f. induced in search coil No. 5 under sustained short circuit at 5 amperes field excitation, 60 cycles per second and series delta connection. Second wave Contactor. Fourth wave: E_{5B} under same conditions, using same vibrator, etc., except machine series Y connected.

Before comparing further the s.s.c. phenomena with the alternator connected Y and delta, see Fig. 28A, also Y with the neutral in, and two-phase, attention should be called to the fact that the two-phase connection was only an imperfect one, the angle



Three-phase two-circuit armature. Two-phase connection giving 81.8 degrees between phases

FIG. 29

between the phases being 81.8 deg. instead of 90. This is clearly shown in Fig. 29 which is self-explanatory. Further as stated in the beginning of this section the armature current under three-phase s.s.c. is sinusoidal, which is not true in this case as may be seen from Fig. 4, first wave.

In view of these two discrepancies it seems rather remarkable that the general wave shapes of the e.m.fs. induced in the search coils under two-phase short-circuit, Fig. 28, are so similar to those obtained with three-phase connection, see Figs. 23, 27 etc., except for some small differences which will be considered presently.

In all the tests with two- or three-phase connection E_{5B} was always found to be considerably larger than E_{1T} so that in many cases it was necessary to insert extra resistance into the vibrator circuit. It will be recalled that this difference in the e.m.fs. induced in coils No. 1 and 5 has already been pointed out in connection with Figs. 7, 20, 22 and Table VII and IX, and it has been ascribed to the fact that the flux density at a surface bounding the bottom of the slots may be larger and more nearly perpendicular to the search coil conductors, than the flux

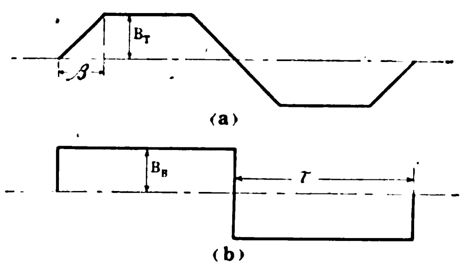


FIG. 30

Assumed flux distribution at top and bottom of slot.

density at the top of the slots. To illustrate this point quantitatively, assume Fig. 30A and 30B to represent the flux distribution at two surfaces bounded by the top and bottom of the slots respectively. For different values of β, the ratio of the 1st and 3rd harmonic of wave 30B to the 1st and 3rd harmonic of Fig. 30A, if $B_T = B_B$, is as follows; (B_B = flux density at bottom of slot. B_T = flux density at top of slot).

β in degrees	1	5	10	20	30
Ratio of firsts	1.022	1.005	1	1.02	1.11
Ratio of thirds	1.005	1.01	1.005	1.205	1.575

If B_B = (1.09 B_T) which is a fair assumption (see Fig. 20) the ratios are as follows:

β in degrees	1	5	10	20	30
Ratio of firsts	1.115	1.09	1.09	1.1	1.21
Ratio of thirds	1.092	1.103	1.37	1.31	1.91

Further, with all connections the crests (2) and (5) columns (7) and (10) Table XV, Figs. 23 and 27 are distinctly larger for E_{5B} than for E_{1T}. Again, the amplitudes of these crests in volts do not differ greatly for delta or for Y connection but are smaller for two-phase connection. For example, crest (2) for E_{1T} is about 3.7 for delta and it is 4 volts for Y, but it is only about 1.8 or 2.6 for two-phase connection. The reason for this will be seen from Fig. 26 which shows that crest (2) is due

TABLE XV.

Data relating to the crest values of the e.m.fs. induced in the stator search coils No. 1, No. 3 and No. 5 under s.s.c. with the machine connected series Y, series △ and two-phase.

No. of oscill.	Field amps.	Kind of s.s.c.	Frequency	Coil e.m.f.	Amplitudes in max. volts of: Crest (1)	Crest (2)	Crest (3)	Crest (4)	Crest (5)	Crest (6)
					See Figs. 27, 28, etc.					
1	2	3	4	5	6	7	8	9	10	11
202	4.95	Y	60	E_{1T}	6.62	4.01	7.88	6.4	3.7	7.56
O A 44	5	Y	54	E_{1T}	5.45	3.25	7.12	5.6	3.25	7.49
O A 88	5	Y	60	E_{1T}	7.21	6.12	11.24	7.17	6.21	11.24
O A 43	5	Y	54	E_{3M}	4.24	4.24	9.48	4.24	4.69	9.48
O A 72	5	Y	54	E_{5B}	6.43	5.01	10.62	6.3	5.28	10.43
O A 89	5	Y	60	E_{5B}	7.47	5.66	11.75	6.89	5.89	11.64
275	4.64	△	60	E_{1T}	7.86	3.73	9.59	8.06	3.73	9.45
275	4.9	△	60	E_{5B}	8.34	6.12	12.32	7.92	6.53	12.67
O A 88	5	△	60	E_{1T}	6.20	3.77	8.05	6.2	3.69	8.05
O A 89	5	△	60	E_{5B}	7.37	5.98	11.32	6.83	5.98	11.54
205	5 +	two-phase	60	E_{1T}	8.23	2.62	8.11	8.11	3.08	8.11
O A 81	4.96	two-phase	60	E_{1T}	7.89	1.85	8.32	7.68	1.85	7.89
O A 86	4.96	two-phase	60	E_{1T}	9.42	1.95	9.74	9.42	1.95	9.74
O A 52	3.16	Y	52	E_{1T}	3.1	1.94	4.08	3.1	1.75	4.37
O A 54	3.16	Y	52	E_{3M}	2.52	2.81	5.91	2.71	2.47	5.91

to the amplitude of the armature reaction which is the same for delta or Y but it is smaller for two-phase connection (imperfect) on account of the distribution factor of the winding.

Taking everything into consideration, it is found that the e.m.fs. induced in rotor coils with two-phase connection are fairly regular; this is further illustrated by wave analysis $V-4$ and $V-5$. Table XIII and also the e_a curves given in Fig. 31.

However, leaving aside, for a moment, all secondary effects it may be well to refer to a graphical explanation given by A.

E. Clayton.[16] He considers an ideal alternator with no magnetic oscillations or secondary effects, no fringing, etc.; the no-load field form may then be assumed to be rectangular and the armature reaction to be portion of a sine wave as indicated in Figs. 32A and 32B. The resultant curve is given in Fig. 32c which resembles in general the waves obtained under s.s.c. conditions.

The rotor exploring coils under s.s.c. show $2\,q = 24$ ripples per cycle due to the teeth. See Table I, column 6 and Figs. 8B and 8c. They also indicate oscillations which repeat themselves

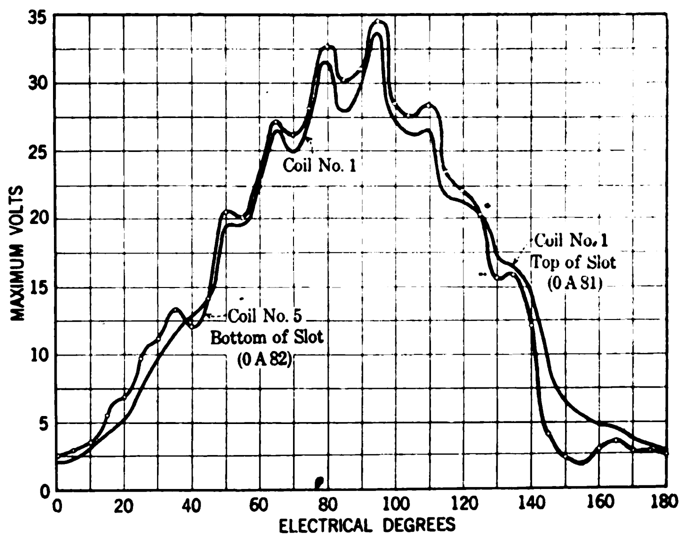


FIG. 31

E_a curves = $E_{fo} - E_r$ = difference between open circuit and s.s.c. e.m.fs. induced in full-pitch top and bottom search coils—field excitation = 5 amperes—periodicity = 60 cycles per second—connection = two-phase.

every 60 deg. See column 5. These as already explained, are due to armature reaction and their jagged unsymmetrical shape may be accounted for as suggested in Fig. 33 where A and B are due to armature reaction and the teeth, and have a frequency of $6\,f$ and $24\,f = 2\,q\,f$, respectively. Their resultant is seen to be similar to the E_{RF} waves Figs. 8B and 8c. In this connection it may be noted that the long flat oscillations which have been

16. The wave shapes obtained with a-c. generators working under steady short-circuit conditions. *Journal, Inst. E. E.*, (London), 1916, Vol. 54, p. 34. This is the first paper, so far as I am aware, to throw any light on this complex subject.

ascribed to the eccentricity of the rotor disappear from the E_{fr} wave under s.s.c. Compare Figs. 4, 5 and 8. This may be explained if the peculiar flux distribution under s.s.c. be considered; taking this to be approximately as represented in Fig. 26 e_r wave, assume that at the position of minimum reluctance the area designated by (A), under crest (1) between $a\ b$, = 83 = B and C = 66 = area under crest (2) between $b\ c$; thus the total net flux per pole under s.s.c. will be 166 − 66 = 100 per cent. Next, at the position of minimum permeance, assume A = 75 = B and C = 50; the net flux per pole is again 150 − 50 = 100 per cent. Obviously under these conditions the e.m.f. due to the eccentricity of the rotor would disappear. However, the areas A, B and C when actually measured were not in the proportion assumed; but it is

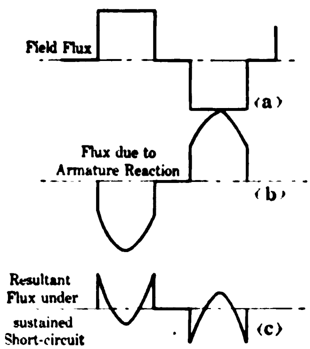


FIG. 32
Flux distribution curves of ideal salient—pole alternator under sustained short circuit

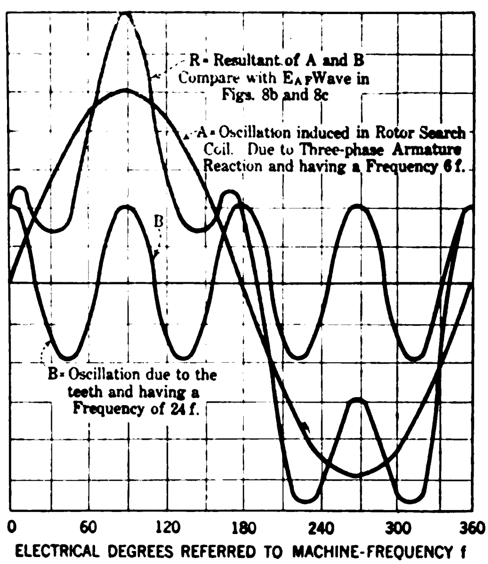


FIG. 33

believed that some such explanation as the one just given is responsible for the disappearance of these oscillations which

occur once in every revolution under no-load or synchronous motor operation.

The e.m.fs. induced in rotor coils No. 8 and 7 with two-phase connection are given in Fig. 4 (third wave) and Fig. 34 (first wave) respectively. E_{RF} = e.m.f. induced in coil No. 7, is nearly 3 times (2.7) as large under two-phase s.s.c. as it is with Y connection. See Table I, columns 8 and 9. As to E_{RC} = e.m.f. induced in coil No. 8, see Fig. 34, it is found to be nearly 6 times (5.7) as large with two-phase s.s.c. as with three-phase s.s.c. Under synchronous motor operation Fig. 8A, E_{RC} is about 0.053 at 59.5 cycles against 0.03 at 50 cycles with three-phase s.s.c. Table I, Test No. 165.

In short, the flux oscillations with two-phase connection are

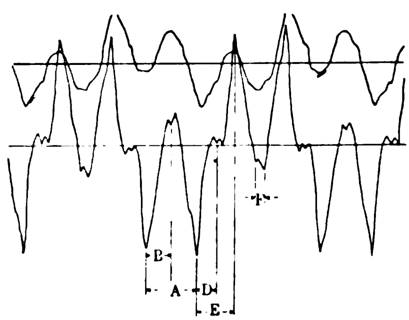


FIG. 34

Oscillogram No. O A 86. Test No. 198. Tables XIV and XV. Sustained short circuit at 4.96 amperes field excitation, and normal speed, two-phase connection. First wave: E_{RC} = e.m.f. induced in rotor coil No. 8. Second wave: E_{1T} = e.m.f. induced in coil No. 1.

very much larger than with three-phase connection. This is believed to be due mainly to the fact that the two phases were not exactly in quadrature.

It can be shown, (see Note C), that if the angle between the two phases is $(90 - \alpha)$ deg., (= 81.8 deg. in our case, see Fig. 30), the resultant armature reaction will consist approximately of (a) a regular travelling wave whose amplitude is approximately equal to the value obtained if $\alpha = 0$. See equation (**56**). (b), it will consist of a wave in *quadrature* to the first and travelling in the opposite direction and at the same speed but having an amplitude $(\sin 2\,\alpha)/2$ of (a). Hence it will be seen, that neglecting other effects, this second rotating field, which is *in quadrature to the first and maximum at* $x_1 = 0$, *i.e., at the coil-side*

of coils No. 7 and 8, will be responsible for the e.m.fs. induced in them under two-phase s.s.c. Further it will account for the peculiarly distorted shape of the E_{RF} wave. This is illustrated in Fig. 35 where the e.m.f. induced in the rotor coil No. 7 is assumed to be due to H_{3R}, $H_3{}^{\alpha}$ and H_{5R}, *i.e.*, regular 3rd space harmonic travelling wave, 3rd space harmonic due to lack of quadrature and regular 5th space harmonic travelling wave. See equations (**59**) and (**62**). The amplitude of these waves is assumed to be 100, 27 and 66 per cent respectively, *i.e.*, $H_3{}^{\alpha} = 0.27\, H_{3R} = (\frac{1}{2} \sin 4\, \alpha)$, approximately. $H_{5R} = H_{3R}\ (4f/6f) = 0.66\ H_{3R}$, where (6 : 4) = ratio of their relative velocities

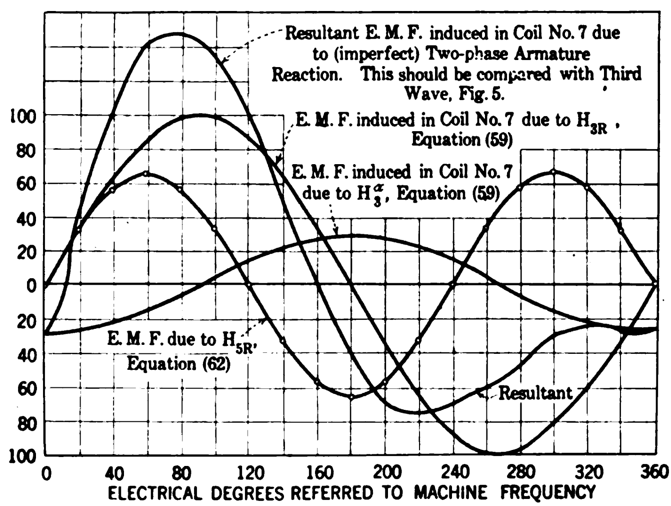
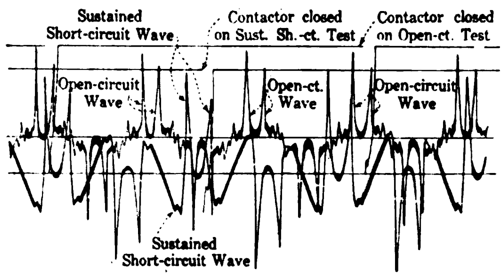


FIG. 35

with respect to the rotor. Thus it is seen that, Fig. 35 explains approximately the peculiar shape of the E_{rf} wave given in Figs. 4 and 34.

Finally considering the e.m.fs. induced under s.s.c. with Y connection, in coils No. 9 and 10, Figs 3 and 3A, we find these to conform to the general wave shape we would expect, according to the explanation given in Section III. In Fig. 36, E_{TT} at no-load and at s.s.c. is given and it is seen that both are characterized by two prominent peaks, and they are quite similar to each other except for the decided difference in shape between a + crest and a − crest. The reason for this will be clear if it be recalled, as explained in detail in Section III, that the portion

of the wave between a + and a − crest is produced while the coil is under the pole-arc; on open-circuit the portion of the *B*-curve under the pole is more or less toothed and it gives rise to little kinks see curve (*b*), Fig. 6. Under s.s.c., however, the



F G. 36

Oscillogram No. O A 61. Test No. 172. Table II. *Exposure No.* 1. Open-circuit run at 60 cycles per second and 4.95 amperes field excitation. First wave: contactor Third wave: E_{TT} = e.m.f. induced in concentrated exploring coil No. 10, on top of tooth. *Exposure No.* 2. Sustained short circuit with series Y connected and same field current and speed as before. Second wave: contactor. Fourth wave: E_{TT}: This shows that there is no displacement in E_{TT} wave under short-circuit condition.

B-curve is very small or even negative at the middle of the pole as indicated by crest (2) Figs. 26, 28, 37 etc. Consequently, as the coil passes from one pole tip to the next its enclosed flux undergoes considerable change, which produces the portion of

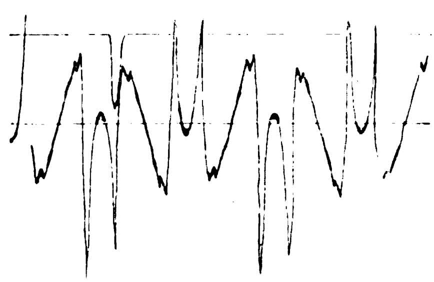


FIG. 37

Oscillogram O A 69. Test No. 180. Sustained short circuit at 5 amperes field excitation, and frequency of 60 cycles per second. Y series connection. First wave: E_{TT} = e.m.f. induced in coil No. 10 on top of tooth.

the curve between a + and a − crest, as indicated in Figs. 36 and 37.

Space forbids considering single phase s.s.c. phenomena; however, for the sake of completeness it may be stated that from a series of tests with the machine delta- or Y-connected

and short-circuited between two terminals, or one terminal and the neutral, (in case of Y) the exploring coil e.m.fs. were found to be fairly similar to those already described. The similarity is rather striking when the presence of complex secondary effects and pulsations of single-phase alternators is considered.

V. Critical Resume and Conclusions

It seems fair to conclude from the above that the sustained short-circuit (s.s.c.) phenomena of alternators in spite of their complexity and the extremely distorted wave-forms to which they give rise, are amenable to the ordinary theories of synchronous generators as given by Blondel, Potier and others. It is only necessary to restrict the usual sweeping simplifying assumptions of so-called text-books in order to arrive at some of the general results given in the preceding pages. It has been shown that unless the field and armature flux waves are sinusoidal the resultant field under s.s.c. will be badly distorted, see for example Figs. 23, 27 etc., for the simple reason that with the very low voltages which obtain under s.s.c. conditions the fundamental is so greatly reduced that the higher harmonics assume a very predominant role. Starting with a field flux-wave consisting of, 1st 100 per cent, 3rd + 10 per cent, 5th + 5 per cent, and a corresponding armature flux curve containing the same harmonics with relative amplitudes of − 95 per cent, + 10 per cent and + 5 per cent, the resultant flux distribution will be given by e_r, Fig. 26; this is not unlike the actual s.s.c. oscillograms given in Figs. 23, 28, etc.

Furthermore it has been shown in Section IV, that with sinusoidal (in time) armature currents the *H*-curve of armature reaction will be sinusoidal, but not so with the *B*-curve; the latter, as is well known will be flat-topped depending upon the degree of saturation, and will further differ from the *H*-curve in that it will be toothed and have different values, and directions with respect to the armature conductors, at a surface bounded by the top of the slots than at a surface bounded by the bottom of the slots. Thus it is clear that from the view-point of s.s.c. phenomena from among the different schemes used for obtaining "sine-wave alternators" the best is the one which attempts to get to the root of the evil and obtain a sinusoidal flux distribution, under the poles to begin with. However, even then harmonics may and will be introduced by armature reaction. It is well in this connection to emphasize the fact that the *B*-curve

of armature reaction will differ more or less from the H-curve producing it for the reasons just given. Consequently the elimination of the higher harmonics from the B-curve (of armature reaction) is very difficult, if not impossible, since even such devices as fractional slots per pole will avail little unless the permeance per unit area across the pole face is made uniform, constant and free from extreme effects of saturation. However, with a thorough understanding of the subject it should be possible to reduce the effects of the B-curve to a negligible quantity.

The magnetic oscillations under load, no-load and s.s.c. conditions are studied not only by means of full-pitch exploring coils placed on the stator and the rotor but also concentrated coils placed on top of a wedge or a tooth and having a pitch equal to a slot-pitch or fraction thereof. See Figs. 3 and 3A.

The principal oscillations observed are:

(1) *Those due to the teeth*; taking the amplitude (a), Fig. 13 as 100 per cent for the coil No. 1 on top of the slot, we find (a) to be 107 per cent for coil No. 3 and 108 per cent for coil No. 5. On the same basis of percentages, (d), Fig. 13, is 24, 31 and 32 per cent respectively for the same coils. See Fig. 7. These oscillations (due to the teeth) decrease under synchronous motor operation. Compare Figs. 7 and 22.

(2) *Oscillations due to the eccentricity of the rotor.* These have a frequency of $(1/p)$ machine-frequency.

(3) *Oscillations due to armature reaction* and having a frequency of 6 times and 4 times machine-periodicity in case of three-phase and two-phase connection. It seems rather remarkable that oscillations (2) disappears under s.s.c.; an explanation of this is given on elsewhere.

(4) *Oscillations due to the pulsations of magnetic reluctance* caused by the salient-pole construction of the machine. These are best illustrated by means of exploring coils placed on top of a slot and on top of a tooth and having a pitch equal to that of a tooth. See Figs. 10, 11, etc. These oscillations are analyzed in detail in Table II and it is seen that the e.m.f. induced in a concentrated coil on top of a tooth is about twice as large as the e.m.f. induced in an exactly similar coil placed on top of a wedge: These oscillations are studied in detail and they give a clear idea of the flux distribution under actual running conditions, which are, of course very important from the point of view of iron losses etc.

Certain pecularities and differences between the e.m.fs. induced in search coils at the top and bottom of slots are considered and, at least, tentative explanations are given. For these the reader can consult sections III and IV.

In regard to different kinds of short-circuits it is shown that there is practically no difference between s.s.c. phenomena with the machine connected delta, Y, and Y with the neutral in. This might have been expected considering the elimination of triple frequency circulating currents due to the $\frac{2}{3}$ pitch armature winding. In case of two-phase connection, however, the armature current is not as sinusoidal as with three-phase connection; the variational e.m.fs. induced in the rotor coils under s.s.c. show very peculiar wave distortion as seen from Fig. 34, first wave, etc. An explanation of this is indicated in Fig. 35.

Before concluding these remarks it may be well to call attention to the bearing of the results given in the paper upon what are considered standard methods of testing large alternators. The thorough understanding of the underlying facts and the collection of quantitative data on the subject for salient as well as non-salient pole generators will throw a great deal of light on efficiency tests, cyclic heat run tests, short-circuit load loss tests, phase-shifting or feeding back method of load tests, etc. In such tests the flux distribution and the flux density at different points of the magnetic circuit is of considerable importance. It seems to the writer that, in such cases, even if it be extremely difficult to devise tests and means of predetermining by calculation certain characteristics of the machine, without actually loading it, it is very desirable to know and understand, as well as possible, the internal reactions so that proper rational allowances may be made. In any case, the detailed analysis of these phenomena seems to be a step in the right direction, and although the application of such information to design and test problems does not fall within the scope of this paper, it may be well to give a simple quantitative illustration of it.

Assume that the open-circuit core loss of an alternator is 2.8 per cent of its rating and that half of this can be charged to hysteresis and the other half to eddy current loss; let the s.s.c.-test loss, excluding friction and windage, be 1.5 per cent. According to the ordinary assumption that the flux distribution under s.s.c. is sinusoidal and 10 per cent of the open-circuit value the hysteresis loss, P_h and the eddy current loss, P_e will be:

$$P_h = \left(\frac{2.8}{2}\right) \cdot \left(\frac{0.10\,B}{B}\right)^{1\cdot 6} \cdot \left(\frac{f}{f}\right)$$

$$= 0.035 \text{ per cent}$$

$$P_e = \left(\frac{2.8}{2}\right) \cdot \left(\frac{0.10\,Bf}{Bf}\right)^2$$

$$= 0.014 \text{ per cent}$$

Consequently, $P_h + P_e = 0.049$ per cent.

Next assume that the fundamental is 5 per cent, the third harmonic is 15 per cent and the fifth 10 per cent; these are fair and very conservative values according to the results of this investigation. Then,

$$P_h = \left(\frac{2.8}{2}\right) \cdot \left(\frac{0.05\,B}{B}\right)^{1\cdot 6} \cdot \left(\frac{f}{f}\right) + \left(\frac{0.15\,B}{B}\right)^{1\cdot 6} \cdot \left(\frac{3\,f}{f}\right) + \left(\frac{0.10\,B}{B}\right)^{1\cdot 6} \cdot \left(\frac{5\,f}{f}\right)$$

$$= 0.114 \text{ per cent}$$

and,

$$P_e = \left(\frac{2.8}{2}\right) \cdot \left(\frac{0.05\,B\,f}{B.f}\right)^2 + \left(\frac{0.15\,B.\,3f}{B.f}\right)^2 + \left(\frac{0.10\,B.\,5f}{B.f}\right)^2$$

$$= 0.45 \text{ per cent}$$

hence, $(P_h + P_e) = 0.564$ per cent.

Thus according to the usual assumption $(P_h + P_e)$ under s.s.c.-tests is negligible, being $(0.049/1.5).\ 100 = 3.3$ per cent, nearly, in this example. But if we take the actual flux distribution under a s.s.c.-test into consideration, and assume the very conservative values taken above for the 3rd and 5th harmonics of the flux-wave, we find that the eddy current and hysteresis losses amount to, $(0.564/1.5).\ 100 = 38$ per cent, nearly, of the total s.s.c.-test losses, *i.e.*, the iron losses are not necessarily negligible.

Finally it seems almost unnecessary to call attention to the necessity of standardizing our terminology. In specifications or technical papers and discussions it is only fair that in case of least ambiguity some qualifying term to be used to specify the kind of short circuit implied. The words "sudden" and "sustained" seem suitable. However, the question of importance is that we should appreciate the great difference between these

two important and complex phenomena of sudden and sustained short circuits and never leave any doubt as to which one is meant.

In conclusion it is a pleasure to the author to acknowledge his indebtedness to the authorities of the Rice Institute for the facilities afforded and particularly the moral support they have lent him. He is also glad to take this opportunity and acknowledge the conscientious and very able assistance of Mr. J. S. Waters, Jr., of the Class of 1917.

SUPPLEMENTARY NOTES

Note A. General E.M.F. Equations

1. *E.M.F. Induced in Stator Search Coils.* As explained in the e.m.f. equations.

$$e = - N \frac{d\phi}{dt} \tag{1}$$

ϕ may be and is usually, a function of the time t, as well as the position x of the coil with respect to the pole. Thus,

$$\frac{d}{dt}(\phi_{x,t}) = \frac{\partial \phi}{\partial x} \cdot \frac{dx}{dt} + \frac{\partial \phi}{\partial t} \cdot \frac{dt}{dt}$$

$$= v \frac{\partial \phi}{\partial x} + \frac{\partial \phi}{\partial t} \tag{2}$$

But, $$\phi_{(x,t)} = \int B_{(x,t)} \cdot l dx \tag{3}$$

whence,

$$e = - N \frac{d\phi}{dt} = - N l \left[v \frac{\partial}{\partial x} \left(\int B\, dx \right) + \frac{\partial}{\partial t} (B\, dx) \right] \tag{4}$$

$$= e_{\text{motional}} + e_{\text{variational}}$$

Strictly speaking, $\phi = \int B\, da.\ \cos(B, da)$, where $da = l dx$

= element of area at which the flux density is B, and $\cos(B, da) = \cos\theta$, is the angle between the vector B and the normal to the elementary surface da; $\cos\theta$ is, of course, ordinarily neglected, except where methods of vector analysis are common. In our attempt to explain certain phenomena, we shall find it necessary to take account of this—which at first may

seem an unnecessary refinement. Thus strictly (**4**) should be written:

$$e = - N l v \frac{\partial}{\partial x} \left[\int B \, dx \cos \theta \right] - N l \frac{\partial}{\partial t} \left[\int B \, dx \cos \theta \right] \qquad \textbf{(4a)}$$

$$= e_{\text{rotational}} + e_{\text{variational}}{}^{17}$$

By means of (**4**) or (**4a**), which are quite general, it is easy to obtain expressions for the rotational and variational e.m.fs. induced in any of the stator or rotor coils. Assuming the flux under the pole to be symmetrical with respect to the interpolar axis, we can write,

$$B = \Big[B_{1m} \sin \left(\pi \frac{x}{\tau} \right) + B_{3m} \sin \left(3 \pi \frac{x}{\tau} \right) + \text{etc.}$$

$$+ B_{1m} \cos \left(\pi \frac{x}{\tau} \right) + B_{3m} \cos \left(3 \pi \frac{x}{\tau} \right) + \text{etc.} \Big] \qquad \textbf{(5)}$$

The rotational e.m.f. induced in a stator coil of N concentrated turns and having an active length of l cm. will be:

$$e_{rot.st.} = - N l v \frac{d}{dx} \int_{x_1}^{x_1+\tau} (B \, dx) \qquad \textbf{(6)}$$

$$= 2 N l v B = 2 N l v \left(B_{1m} \cdot \sin \left(\frac{x}{\tau} \pi \right) + \text{etc.} \right) \qquad \textbf{(7)}$$

since according to the assumption made in (**5**) even harmonics are absent, and in case of a full-pitch coil B at $x_1 = - B$ at $(x_1 + \tau)$. For a short-pitch coil (**7**) must be multiplied by the pitch factor.

In order to find expressions for the variational e.m.fs. let us make the assumption that the *flux variations are sinusoidal*. This is a very convenient assumption, since our equations already involve sine functions, and it is reasonably correct, as indicated by experience, because we are dealing with a *correction term* to be *added* to the comparatively large rotational e.m.f. Thus if $2\,q$ = number of slots per pair of poles, p, and (f/p) = speed of the machine in rev. per sec., obviously, $2\,q\,(f/p)$ will be the number of slots per second passing a given point x_1; this will set

17. S. J. Barnett, Electromagnetic Theory, pp. 333 to 340.

up an oscillation of small amplitude and of frequency $2\,q\,f$, which will be expressed in mathematical symbolism by:

$$B_{pul} = B\,(\eta \cos (2\,q\,\omega\,t)\,) \tag{8}$$

Neglecting the higher harmonics of the B curve, see (5), we get'

$$B_{pul} = \eta\,B_1 \left(\sin\left(\frac{x}{\tau}\,\pi\right)\right)(\cos(2\,q\,\omega\,t)\,) \tag{9}$$

whence,

$$\frac{\partial}{\partial t}\,(B_{pul})' = -\,\eta\,B_1\,2\,q\,\omega\left(\sin\left(\frac{x}{\tau}\,\pi\right)\right)(\sin(2\,q\,\omega\,t)\,) \tag{10}$$

and according to the second term of the right hand member of (4) the variational e.m.f. is proportional to:

$$\int_x^{x+\tau} \frac{\partial B_{pul}}{\partial t}\,dx = -\,\eta\,B_1\,4\,q\,\omega\,\frac{\tau}{\pi}\left(\cos\frac{x}{\tau}\,\pi\right)(\sin 2\,q\,\omega\,t) \tag{11}$$

To find the e.m.f. induced in any armature conductor it must be remembered that owing to the relative movement between armature and field,

$$x = v\,t = (2\,\pi\,r)\,(\text{r.p.s.})\,t$$

$$= 2\left(\frac{2\,\pi\,r}{2\,p}\right)(\text{r.p.s.})\,t = (2\,\tau\,f)\,t = \left(\omega\,\frac{\tau}{\pi}\right)t \tag{12}$$

where r = radius of rotor, so that,

$$e_{pul.st.} = -\,N\,l\,\frac{\partial}{\partial t}\int B\,dx$$

$$= 4\,N\,l\,\frac{\tau}{\pi}\,q\,\omega\cdot\eta\,B_1\,(\cos\omega\,t)\,(\sin 2\,q\,\omega\,t) \tag{13}$$

$$= 4\,N\,l\,q\,\omega\,\frac{\tau}{\pi}\,\eta\,B_1\,[\sin(2\,q\,\omega + 1)\,\omega\,t$$

$$+ \sin(2\,q - 1)\,\omega\,t] \tag{14}$$

To find analytical expressions for the static or variational e.m.f. in an armature conductor due to the to-and-fro swing of the flux, we shall assume that the B-curve is constant in magnitude, but it moves across the pole-face according to simple harmonic motion, at a frequency of $2\,q\,f$. Hence neglecting the higher harmonics of (5) we may write,

$$B_{sw} = B_1\left[\sin\frac{\pi}{\tau}\,(x - \epsilon \sin 2\,q\,\omega\,t)\right] \tag{15}$$

where $2\,q\,\omega$ is the angular velocity and ϵ the amplitude of the variations.

Differentiating (**15**) with respect to t and making the reasonable assumption that,

$$\cos\left(\frac{\pi}{\tau}\;\epsilon\sin 2\,q\,\omega\,t\right) = 1, \text{ and}$$

$$\sin\left(\frac{\pi}{\tau}\;\epsilon\sin 2\,q\,\omega\,t\right) \doteq \frac{\pi}{\tau}\;\epsilon\,(\sin 2\,q\,\omega\,t)$$

we obtain:

$$\frac{\partial B_{sw}}{\partial t} = -\,B_1\left[\cos\frac{\pi}{\tau}\,(x - \epsilon\sin 2\,q\,\omega\,t)\right]\left[2\,\epsilon\,q\,\omega\,\frac{\pi}{\tau}\,\cos 2\,q\,\omega\,t\right] \tag{16}$$

and

$$\int_x^{x+\tau}\frac{\partial B_{sw}}{\partial t}\,d\,x = [4\,\epsilon\,B_1\,q\,\omega\cos(2\,q\,\omega\,t)]\left[\sin\frac{\pi}{\tau}\,(x - \epsilon\sin 2\,q\,\omega\,t)\cos\frac{x}{\tau}\,\pi\right] \tag{17}$$

As before, to find the variational e.m.f. in a given armature conductor due to the flux-swing, substitute,

$$x = (2\,f\,\tau\,t) = \left(\omega\,\frac{\tau}{\pi}\,t\right)$$

Thus,

$$\begin{aligned} e_{sw.st.} &= -\,4\,N\,l\,q\,\omega\,(\epsilon\,B_1)\,(\cos 2\,q\,\omega\,t)\,[\sin(\omega\,t - \epsilon\sin 2\,q\,\omega\,t)\cos\omega\,t] \\ &= -\,4\,N\,l\,q\,\omega\,(\epsilon\,B_1)\Big[\{\sin(2\,q + l)\,\omega\,t - \sin(2\,q - l)\,\omega\,t\} \\ &\quad - \left\{\frac{\epsilon}{2}\sin(4\,q + 1)\,\omega\,t + \sin(4\,q - 1)\,\omega\,t\right\}\Big] \end{aligned} \tag{18}$$

2. *E.M.Fs. Induced in Field Exploring Coils.* Equation (**7**) gives the rotational e.m.f. induced in a coil of N concentrated turns having a relative speed v with respect to B. Evidently this is zero for a coil placed on the rotor, and therefore,

$$e_{mot.r.} = 0 \tag{19}$$

To find the variational e.m.f. due to flux pulsations in a field (rotor) search coil whose coil-side is at any point x_1, simply substitute $x = x_1$ in (**13**). Thus,

$$e_{pul.r} = 4\,N\,l\,q\,\omega\,(n\,B_1)\cos\left(\frac{\pi}{\tau}\,x_1\right)(\sin 2\,q\,\omega\,t) \tag{20}$$

Similarly from (**17**) and (**4**) we get,

$$\begin{aligned} e_{sw.r.} &= -\,N\,l\,\frac{\partial}{\partial t}\int B\cdot d\,x \\ &= 4\,N\,l\,q\,\omega\,(\epsilon\,B_1)\,(\cos 2\,q\,\omega\,t) \\ &\quad \left[\left\{\sin\left(\frac{\pi}{\tau}\,x_1 - (\epsilon\sin 2\,q\,\omega\,t)\right)\right\}\cos\frac{\pi}{\tau}\,x_1\right] \end{aligned} \tag{21}$$

For coils No. 7 and 8, $x_1 = 0$, whence we obtain directly (**22**) and (**23**) from (**20**) and (**21**) respectively, as given in the first part of the paper:

$$e_{sw.r.} = 2\,N\,l\,q\,\omega\,\epsilon^2\,B_1\sin(4\,q\,\omega\,t) \tag{22}$$

and,

$$e_{pul.r.} = 4\,N\,l\,q\,\omega\,\eta\,B_1\sin(2\,q\,\omega\,t) \tag{23}$$

Note B

1. *Theoretical Investigation of Armature Reaction.* Make the reasonable assumption (as shown on p. 15) that the armature current under s.s.c. is sinusoidal (with respect to time). Further assume that the armature winding of say, a three-phase alternator is sinusoidally distributed (in space) as schematically represented in Fig. 17. If one of the phase windings were supplied with d-c. the magnetic field intensity H, at any point θ_{gsr}, geometrical space radians or x centimeters, from the axis of reference, see Fig. 17, would be,

$$H_1' = \gamma\,I_{d.c.}\,(N_{max}\cos p\,\theta_{gsr}) = \gamma\,I_{d.c.}\,N_{max}\cos\left(\frac{x}{\tau}\pi\right) \tag{24}$$

where, γ = constant, and $\left(\frac{x}{\tau}\,\pi\right) = p\,\theta_{gsr}$ = electrical space radians. Similarly for the other phases:

$$\left.\begin{aligned} H_1'' &= \gamma\,I_{d.c.}\,N_m\cos\left(\frac{x'}{\tau}\,\pi\right) = \gamma\,I_{d.c.}\,N_m\cos\left(\frac{x}{\tau}-\frac{2}{3}\right)\pi \\ H_1''' &= \gamma\,I_{d.c.}\,N_m\cos\left(\frac{x''}{\tau}\,\pi\right) = \gamma\,I_{d.c.}\,N_m\cos\left(\frac{x}{\tau}-\frac{4}{3}\right)\pi \end{aligned}\right\} \tag{25}$$

When these windings are supplied with balanced three-phase currents the resultant field intensity due to armature reaction will be:

$$H_1' = \gamma\,[I_m \cos \omega t] \left[N_m \cos \frac{x}{\tau}\,\pi\right] \tag{26}$$

$$H_1'' = \gamma \left[I_m \cos\left(\omega t - \frac{2}{3}\,\pi\right)\right] \left[N_m \cos\left(\frac{x}{\tau} - \frac{2}{3}\,\pi\right)\right] \tag{27}$$

$$H_1''' = \gamma \left[I_m \cos\left(\omega t - \frac{4}{3}\,\pi\right)\right] \left[N_m \cos\left(\frac{x}{\tau} - \frac{4}{3}\,\pi\right)\right] \tag{28}$$

whence by trigonometry,

$$\begin{aligned} H = H_1' + H_1'' + H_1''' &= \frac{3}{2}\,H_m \cos\left(\omega t - \frac{x}{\tau}\pi\right) \\ &= \frac{3}{2}\,\gamma\, I_m \cos\left(\omega t - \frac{x}{\tau}\,\pi\right) \end{aligned} \tag{29}$$

This gives the resultant field intensity due to armature reaction and it will be recognized to be the well known equation of a travelling wave which is a function of the time t, as well as the space position x, and whose maximum, H_m, occurs when $\omega t = \left(\frac{x}{\tau}\,\pi\right)$; in other words, whose maximum H_m travels at a speed $(x/t) = (\omega\,\tau/\pi) = (2\,f\,\tau)$, which is the peripheral speed of the rotor. See (**12**). Next, consider the case of N conductors per slot and one slot per pole per phase carrying $I_{dc.}$ amperes. Evidently, as indicated in Fig. 18 the field intensity H, will be rectangular in shape and may be represented by the series:

$$H = \frac{4}{\pi}\,Y_m \left[\sin\left(\frac{x}{\tau}\,\pi\right) + \frac{1}{3}\sin\left(3\,\frac{x}{\tau}\,\pi\right) + \ldots\right] \tag{30}$$

Equation (**30**) takes the place of (**24**) and similar expressions can be written out for the other phases, corresponding to (**25**) and (**26**). However, without going any further into this, suffice to call attention to the references given in foot-note (**13**) and state that if the non-sinusoidally distributed winding represented in Fig. 18, be supplied with balanced a-c. instead of d-c., expressions exactly analogous to (**26**), (**27**) etc. will be obtained. Combining these trigonometrically, we get (**32**), (**33**) etc. which were given in the first part, in section IV.

2. *E.M.F. Induced in Rotor and Stator Exploring Coils by the Armature Reaction.* It is a simple matter, now to obtain general expressions for the e.m.fs. induced in the different search coils, if we assume that the B-curve is sinusoidal; the rotational e.m.f. of a stator coil whose coil-side is at a fixed distance x_1 from the origin, see Fig. 6 will be according to (4):

$$e_{rot.st} = -N\,l\,v\,\frac{\partial}{\partial x}\int B\,d\,x \tag{36}$$

$$= -N\,l\,(2f\tau)\,\frac{\partial}{\partial x}\int \frac{3}{2}\,B_a\cos\left(\omega\,t - \frac{x_1}{\tau}\,\pi\right)\cdot d\,x \tag{37}$$

$$= -N\,l\,(2f\tau)\left(\frac{3}{2}\,B_a\right)\cos\left(\omega\,t - \frac{x_1}{\tau}\,\pi\right) \tag{38}$$

This is a sinusoidal e.m.f. of fundamental frequency and having a phase angle $\left(\frac{x_1}{\tau}\,\pi\right)$ with respect to the origin.

The fifth space harmonic of armature reaction will give:

$$e_{rot.st.} = -N\,l\,\frac{2f\tau}{5}\cdot\frac{\partial}{\partial x}\int\frac{3}{2}\,B_a\cos\left(\omega\,t + \frac{5\,x_1}{\tau}\,\pi\right) \tag{39}$$

$$= -N\,l\,\frac{2f\tau}{5}\cdot\frac{3}{2}\,B_a\cos\left(\omega\,t + \frac{5\,x_1}{\tau}\,\pi\right) \tag{40}$$

i.e., an e.m.f. of fundamental machine frequency and having a phase angle $(6\,x_1/\tau)\,\pi$ with respect to the origin. Similar expressions may be derived for all other harmonics.

However, as already explained, the sinusoidal H-curve produced by the armature reaction will give rise to a distorted B-curve. This will produce in the stator coils a motional e.m.f. which will contain higher *time harmonics*. To find analytical expressions for these e.m.fs. (due to a distorted gliding or rotating B-curve) it will be convenient to assume the B-curve as stationary and the exploring coils revolving at the same speed in the opposite direction. In this manner the problem is reduced to the one already considered in Note A, and it seems hardly necessary to derive equations for them here.

As to the e.m.fs. induced in the rotor search coils (due to armature reaction), it is clear that the fundamental travelling

wave given by (**32**), will induce no e.m.f. The 3rd harmonic will, of course, be zero for a three-phase machine. See (**33**).

To find the motional e.m.f. induced in a rotor coil due to the fifth space harmonic B_5,

$$B_5 = (1/2)\ B_a \cos\ (\omega\, t + 5\, x\, \pi/\tau) \tag{41}$$

it must be remembered that x increases at the rate of $2\, f\, \tau$ with respect to the rotor. Thus substituting in (**41**),

$$\omega\, t = \pi\, x/\tau = (\pi/\tau)\ 2\, f\, \tau\, t \tag{42}$$

we obtain,

$$B_5 = (3/2)\ B_a\ (\cos 6\ \omega\, t) \tag{43}$$

Similarly,

$$B_7 = (3/2)\ B_a\ (\cos 6\ \omega\, t) \tag{44}$$

That is, the 5th and 7th space harmonics though of fundamental frequency with respect to the stator are of sextuple frequency with respect to the rotor. This will be clear when it is considered that the 5th space harmonic glides backward at a speed $(2\, f\, \tau/5)$ while the seventh travels forward at a speed $(2\, f\, \tau/7)$. Assuming for convenience the rotor as stationary, it is evident, that the relative speed between the rotor and these gliding fields will be:

$$(2\, f\, \tau) - \left(-\ \frac{2\, f\, \tau}{5}\right) = 6\left(\frac{2\, f\, \tau}{5}\right) \tag{45}$$

and

$$2\, f\, \tau - \left(+\ \frac{2\, f\, \tau}{7}\right) = 6\left(\frac{2\, f\, \tau}{7}\right) \tag{46}$$

respectively. The pole pitches τ_5 and τ_7 of the fifth and seventh fields are $(\tau/5)$ and $(\tau/7)$, and the corresponding number of pairs of poles are $5\, p$ and $7\, p$ respectively. Consequenty the frequency of the e.m.fs. induced in a rotor coil by them will be:

$$f_5 = (\text{r.p.s.})_5\ (p_5) = (\text{speed})_5\left(\frac{1}{2\, \tau\, p}\right)(5\, p) \tag{47}$$

$$= 6\left(\frac{2\, \tau\, f}{5}\right)\cdot\left(\frac{1}{2\, \tau\, p}\right)(5\, p) = 6\, f \tag{48}$$

Similarly for the 7th space harmonic,

$$f_7 = 6\left(\frac{2\, \tau\, f}{7}\right)\left(\frac{1}{2\, \tau\, p}\right) 7\, p = 6\, f \tag{49}$$

In general for the $(6\, n - 1)$ *th* space harmonic which travels backward with respect to the fundamental,

$$f_{(6n-1)} = 6\,n\Big(2\tau f/(6\,n-1)\Big)\Big((6\,n-1)\,p/2\tau\,p\Big) = 6\,n\,f \qquad (50)$$

and for the $(6\,n+1)\,t\,h$ harmonic,

$$f_{(6n+1)} = 6\,n\,\Big(2\tau f/(6\,n+1)\Big)\Big((6\,n+1)\,p/2\tau\,p\Big) = 6\,n\,f \quad (51)$$

Thus the 11th and 13th will give rise to rotor e.m.fs. having periodicities of $12\,f$, and so on for the others.

In case of two-phase alternators the 3rd and 5th will give rise to e.m.fs. of (4. machine frequency). The sèventh and ninth will produce e.m.fs. of (8. machine frequency), etc.

However, as shown by the oscillograms given before, the rotor search coils indicate only pulsations having periodicities of $6\,f$ in case of three-phase connection and $4\,f$ in case of two-phase connection. In concluding this note attention may be called to the fact that the above analysis of armature reaction and the e.m.fs. induced by it in the stator and rotor coils is applicable to induction motors; as a matter of fact it is a little difficult for the writer to understand why standard texts do not treat armature reaction in alternators etc. in exactly the same way as the rotating fields of induction motors, as it has been done above, because it is more convenient and lends itself better to the derivation of quantitative expressions for the e.m.fs. induced in the stator and rotor by armature reaction alone.

Note C. Direct Component of Armature Reaction of an Imperfect Two-Phase Alternator

As already explained in detail the resultant magnetic field intensity due to balanced two-phase currents flowing through sinusoidally distributed two-phase windings will be given by:

$$H_1' = H_1' + H_1'' = H_m\Big[\{\cos\,\omega\,t\}\left\{\cos\left(\frac{x}{\tau}\,\pi\right)\right\}$$

$$+\left\{\cos\left(\omega\,t+\frac{\pi}{2}\right)\right\}\left\{\cos\left(\frac{x}{\tau}\,\pi+\frac{\pi}{2}\right)\right\}\Big] \qquad (52)$$

Now in case of an imperfect machine which has a displacement between phases of $\left(\frac{\pi}{2}-\alpha\right)$ deg. instead of $\frac{\pi}{2}$, the sum of H_1' and H_1'' will be:

$$H_1 = H_m \left[\{\cos \omega t\} \left\{ \cos \left(\frac{x}{\tau} \pi \right) \right\} \right.$$

$$\left. + \left\{ \cos \left(\omega t + \frac{\pi}{2} - \alpha \right) \right\} \left\{ \cos \left(\frac{x}{\tau} \pi + \frac{\pi}{2} - \alpha \right) \right\} \right] \quad (53)$$

$$= H_m \left[\frac{1}{2} \cos \left(\omega t + \frac{x}{\tau} \pi \right) + \frac{1}{2} \cos \left(\omega t - \frac{x}{\tau} \pi \right) - \right.$$

$$\left. \frac{1}{2} \cos \left(\omega t + \frac{x}{\tau} \pi - 2\alpha \right) + \frac{1}{2} \cos \left(\omega t - \frac{x}{\tau} \pi \right) \right] \quad (54)$$

$$= H_m \left[\left\{ \cos \left(\omega t + \frac{x}{\tau} \pi \right) \right\} \left\{ \frac{1}{2} - \frac{\cos 2\alpha}{2} \right\} \right.$$

$$\left. - \left\{ \frac{\sin 2\alpha}{2} \right\} \left\{ \sin \left(\omega t + \frac{x}{\tau} \pi \right) \right\} + \left\{ \cos \left(\omega t - \frac{x}{\tau} \pi \right) \right\} \right] \quad (55)$$

or approximately,

$$H_1 = H_m \left[\cos \left(\omega t - \frac{x}{\tau} \pi \right) - \left(\frac{\sin 2}{2} \right) \left(\sin \left(\omega t + \frac{x}{\tau} \pi \right) \right) \right] \quad (56)$$

= regular fundamental (space) wave gliding forward + a second wave due to lack of quadrature, and gliding backwards.

Further it can be shown, as it was explained in Note B, that with ordinary non-sinusoidally distributed windings, supplied with alternating current of fundamental frequency, (with respect to time) there will be a 3rd space harmonic of the form, $H_3 = H_3' + H_3''$,

$$H_3 = H_a \left[\{\cos (\omega t)\} \left\{ \cos \left(\frac{3x}{\tau} \pi \right) \right] \right.$$

$$\left. + \left\{ \cos \left(\omega t + \frac{\pi}{2} - \alpha \right) \right\} \left\{ \cos \left(\frac{3x}{\tau} \pi + \frac{3\pi}{2} - 3\alpha \right) \right\} \right] \quad (57)$$

Translating (**57**) into words we shall find that it simply represents the field intensity due to a current of fundamental pulsation ω flowing through the 3rd harmonic of a non-sinusoidal winding. Simplifying this equation, we get,

$$H_3 = H_a \Big[\Big\{ \cos \Big(\omega t + \frac{3x}{x} \pi \Big) \Big\} \Big\{ \Big(\frac{1}{2} + \frac{\cos 4\alpha}{2} \Big) \Big\}$$

$$+ \Big\{ \cos \Big(\omega t - \frac{3x}{\tau} \pi \Big) \Big\} \Big\{ \Big(\frac{1}{2} - \frac{\cos 2\alpha}{2} \Big) \Big\}$$

$$+ \Big\{ \sin \Big(\omega t + \frac{3x}{\tau} \pi \Big) \Big\} \Big\{ \Big(\frac{\sin 4\alpha}{2} \Big) \Big\}$$

$$- \Big\{ \sin \Big(\omega t - \frac{3x}{\tau} \pi \Big) \Big\} \Big\{ \frac{\sin 2\alpha}{2} \Big\} \Big] \qquad \textbf{(58)}$$

or approximately,

$$H_3 = H_a \Big[\cos \Big(\omega t + \frac{3x}{\tau} \pi \Big)$$

$$+ \Big(\sin \Big(\omega t + \frac{3x}{\tau} \pi \Big) \Big) \Big(\frac{1}{2} \sin 4\alpha \Big)$$

$$+ \Big(\sin \Big(\omega t - \frac{3x}{\tau} \pi \Big) \Big) \Big(\frac{1}{2} \sin 2\alpha \Big) \Big] \qquad \textbf{(59)}$$

$= H_{3R} + H_3{}^{\alpha} + H_{31}{}^{\alpha}$

= regular third space harmonic travelling backward at a speed $2 f \tau / 3$. + a second wave due to lack of quadrature and in quadrature to the first and travelling in the same direction and at the same speed as the first. + a third wave due to lack of quadrature and in phase with the second but travelling forwards, at the same speed as the first two.

If desired the third wave in (**59**), $H_{31}{}^{\alpha}$, may be neglected, and H_3 be taken equal to H_{3R} and $H_3{}^{\alpha}$.

Exactly as before for the 5th space harmonic, due to a sine wave of current of fundamental pulsation ($\omega = 2 \pi f$), we have,

$$H_5 = H_a \Big[\{ \cos (\omega t) \} \Big\{ \cos \Big(\frac{5x}{\tau} \pi \Big) \Big\}$$

$$+ \Big\{ \cos \Big(\omega t + \frac{\pi}{2} - \alpha \Big) \Big\} \Big\{ \cos \Big(\frac{5x}{\tau} \pi + \frac{5\pi}{2} - 5\alpha \Big) \Big\} \Big] \qquad \textbf{(60)}$$

Simplifying this, we find,

$$H_5 = H_a \Bigg[\left\{ \cos \left(\omega t + \frac{5x}{\tau} \pi \right) \right\} \left\{ \frac{1}{2} - \frac{\cos 6\alpha}{2} \right\}$$

$$+ \left\{ \cos \left(\omega t - \frac{5x}{\tau} \pi \right) \right\} \left\{ \frac{1}{2} + \frac{\cos 4\alpha}{2} \right\}$$

$$- \left\{ \sin \left(\omega t + \frac{5x}{\tau} \pi \right) \right\} \left\{ \frac{1}{2} \cdot \sin 6\alpha \right\}$$

$$- \left\{ \sin \left(\omega t - \frac{5x}{\tau} \pi \right) \right\} \left\{ \frac{1}{2} \cdot \sin 4\alpha \right\} \Bigg] \qquad \textbf{(61)}$$

or approximately,

$$H_5 = H_a \Bigg[\cos \left(\omega t - \frac{5x}{\tau} \pi \right)$$

$$- \left(\sin \left(\omega t + \frac{5x}{\tau} \pi \right) \right) \frac{1}{2} \cdot \sin 6\alpha$$

$$- \left(\sin \left(\omega t - \frac{5x}{\tau} \pi \right) \right) \frac{1}{2} \cdot \sin 4\alpha \Bigg] \qquad \textbf{(62)}$$

= a regular fifth space harmonic, travelling forward at a speed $2 f \tau / 5$. + a second wave in quadrature to the first and travelling backward at the same speed. + a third wave in quadrature to the first and gliding forward at the same speed.

As in (**59**) H_5 may be taken equal to $(H_{5R} + H_5^{\alpha})$ and the third wave be neglected. Similar expressions for other space harmonics may be derived by exactly the same procedure. Furthermore, in all the above we have assumed the current to be of the form $I_m \cos \omega t$. If the current contains higher time harmonics the resultant armature reaction may be found in a similar manner

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THE AUTOMATIC HYDROELECTRIC PLANT

BY J. M. DRABELLE AND L. B. BONNETT

ABSTRACT OF PAPER

The automatic hydroelectric generating station of the Iowa Railway and Light Company at Cedar Rapids, Iowa, is a radical step in advance in the elimination of operator's wages in a station of appreciable size, without sacrificing complete control.

This station consists of three 400-kw., 500-kv-a., 60-rev. per min., 2300-volt, vertical generating units, tied in to a system, of which the main generating station contains about 20,000 kv-a. in steam turbo-generators. One striking feature is the entire omission of the usual governors, the waterwheel gates being motor driven and controlled by contact-making ammeters. Each unit has its individual control panel, consisting of the necessary contactors and relays to connect it to the bus at the proper time. A motor-driven drum controller gives the proper time element between the different steps in the operation of placing the generator on the line. Any generator can be started either by a float switch when the pond level reaches the proper height or by a remote control button in the steam station. The starting of the first generator throws on the line the motor of one of the two exciter sets, and the generator cannot be connected to the bus until the excitation voltage has reached the normal value. The waterwheel gates are then partly opened and the generator comes up to approximately normal speed. It is then connected to the bus without field through an iron-core reactance. Then a weak field is applied. Next it is raised to full normal value, and then the reactance is short-circuited. The contact-making ammeter opens the gates to full gate opening and the generator then carries full load in about 40 seconds after either the control button is closed or the float switch is closed.

ON October 2nd there was placed in operation at Cedar Rapids, Iowa, the automatic hydroelectric plant of the Iowa Railway and Light Company. This plant represents a further development of the automatic substation first described in a paper by Messrs. Allen and Taylor in the A.I.E.E. TRANSACTIONS, Volume XXXIV, Part 2, page 1801.

The station operates with no attendant and the different generating units start or stop, depending on the flow of the river or can be started and kept running by remote control from the main steam station, as described in detail later.

The building is 112 ft. (34.13 m.) long, 41 ft. (12.49 m.) wide and has a depth to rock bottom at the bottom of the draft

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tubes of 37 ft. (11.27 m.). The substructure is of concrete; the superstructure is 30 ft. (9.14 m.) high above the water table of the building and is constructed of Bedford Limestone. The interior of the building is finished in yellow brick and the floor in red tile. The exterior is shown in Figs. 1 and 2. There are installed three 500-kv-a. 80 per cent power factor, 60-cycle two-phase, 2300-volt, 60-rev. per min. generators, of the vertical type. They are driven by waterwheels rated 540 b. h. p., 60 rev per min. under a 10 ft. (3 m.) head, the operating head varying from 8 ft. (2.43 m.) to 11 ft. (3.35 m.). The runners are of the Francis type, having a diameter of 171 in. (4.33 m.). The rotating element is supported by a thrust bearing at the top, supplied with oil by a pump driven from the generator shaft.

The dam consists of nine spillway sections, each 60 ft. (18.28 m.) long with automatic flashboards, the total over-all length being 600 ft. (182.88 m.). The dam is shown in Fig. 3.

There are two General Electric Induction motor-driven exciter sets rated 100 kw. 125 volt. each capable of carrying the entire excitation of the total development, namely, that of four generators. The motors are rated 150-h.p., 2300-volt, two-phase, 60-cycle, 1200-rev. per min. and are designed to be started by the application of full voltage at standstill.

The plant is designed to operate in parallel with the 19,000-kw. steam turbogenerating station of the Iowa Railway and Light Company, the steam plant being located at a distance of 3300 ft. (1005.84 m.) from the hydroelectric plant. The stations are tied together by one underground line consisting of two 600,000-cir. mil, two-conductor, concentric, 7500-volt, varnished cambric, lead-covered cables.

The different generating units may be started and stopped either automatically, depending on the rise or fall of the water level in the river; or by remote control from the steam station when the capacity is needed. To accomplish the latter, a bench board section, shown in Fig. 5, was installed in the steam plant. On this, for each generator, there are provided three single-throw and one double-throw control buttons, the purpose of which will be explained later. All control wires between the stations are bunched in a multi-conductor, lead-covered cable consisting of fifty No. 12 and four No. 4 B. & S., rubber-covered wires.

The same benchboard contains for each generator an in-

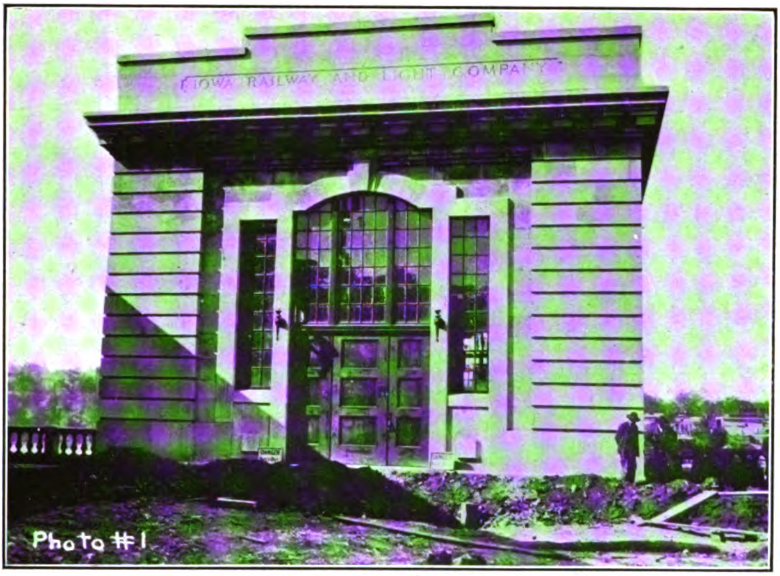
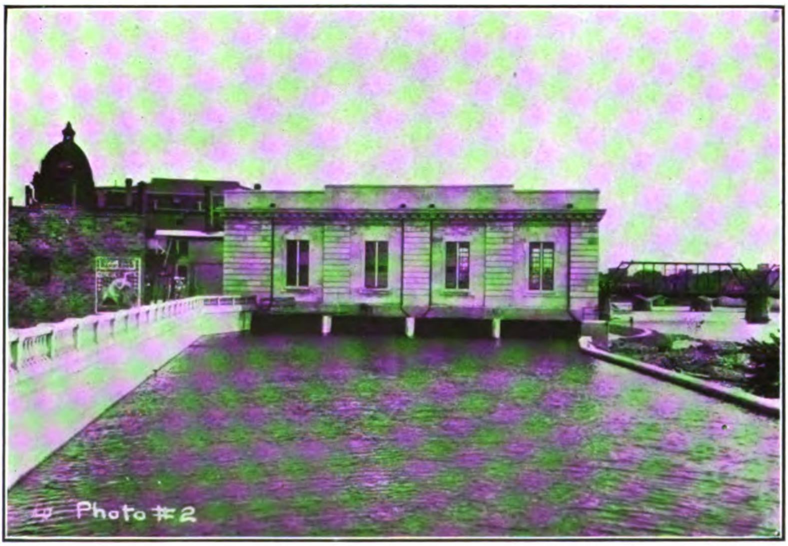


FIG. 1—EXTERIOR OF STATION—FRONT VIEW



[DRABELLE AND BONNETT]

FIG. 2—EXTERIOR OF STATION—REAR VIEW

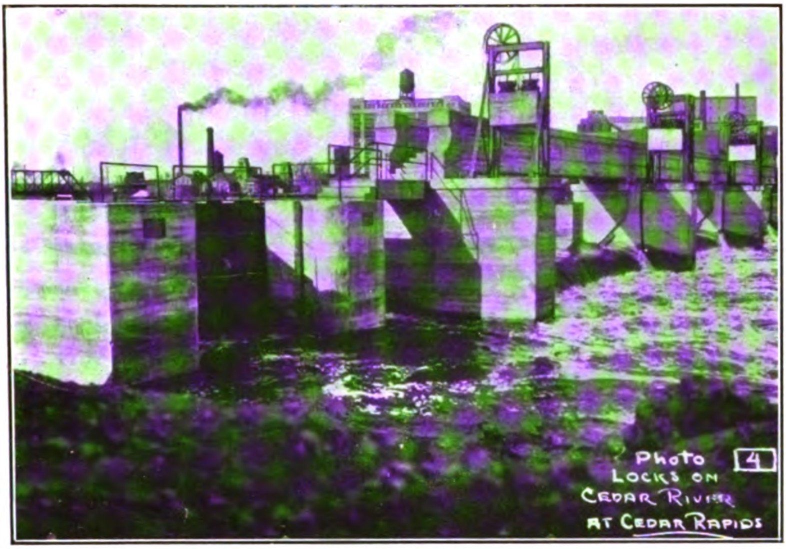
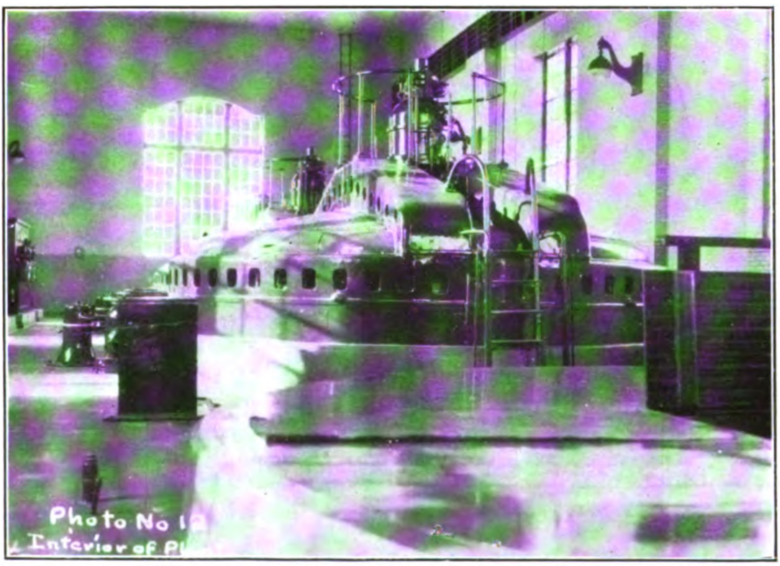


FIG. 3—LOCKS ON CEDAR RIVER AT CEDAR RAPIDS



[DRABELLE AND BONNETT]

FIG. 4—INTERIOR OF STATION

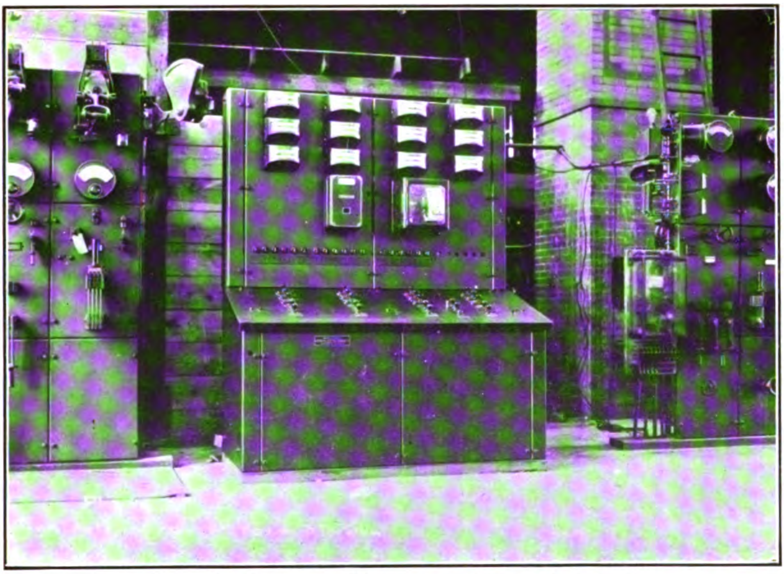
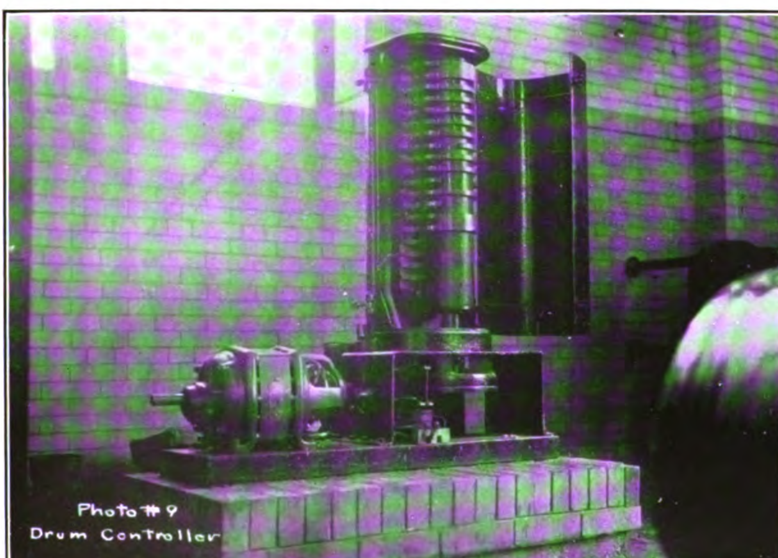


FIG. 5—CONTROL BOARD AT STEAM STATION



[DRABELLE AND BONNETT]

FIG. 6—DRUM CONTROLLER

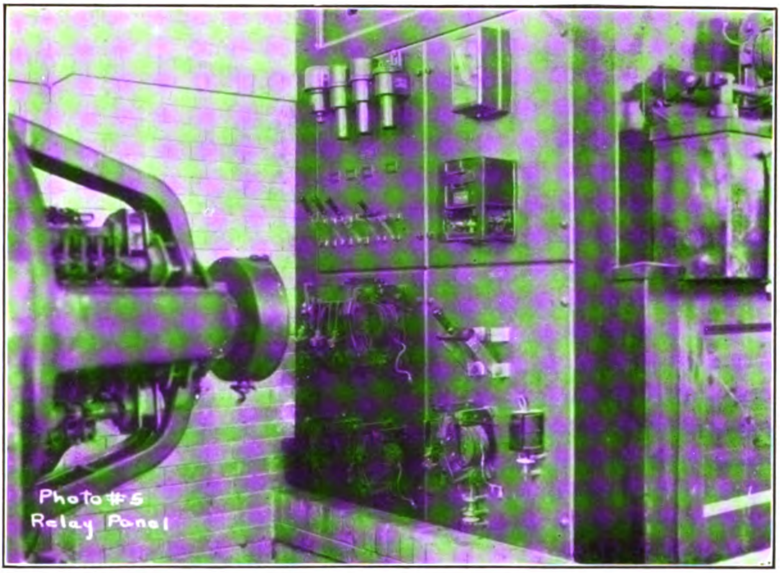
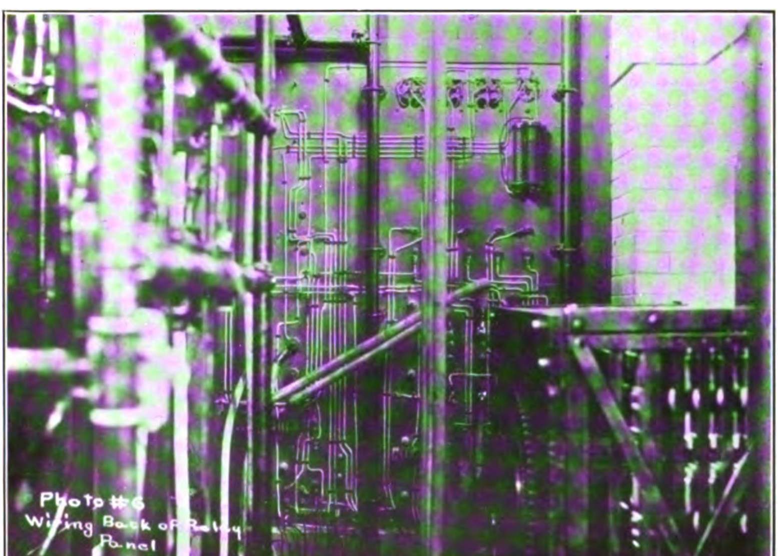


FIG. 7—RELAY PANEL



[DRABELLE AND BONNETT]

FIG. 8—WIRING BACK OF RELAY PANELS

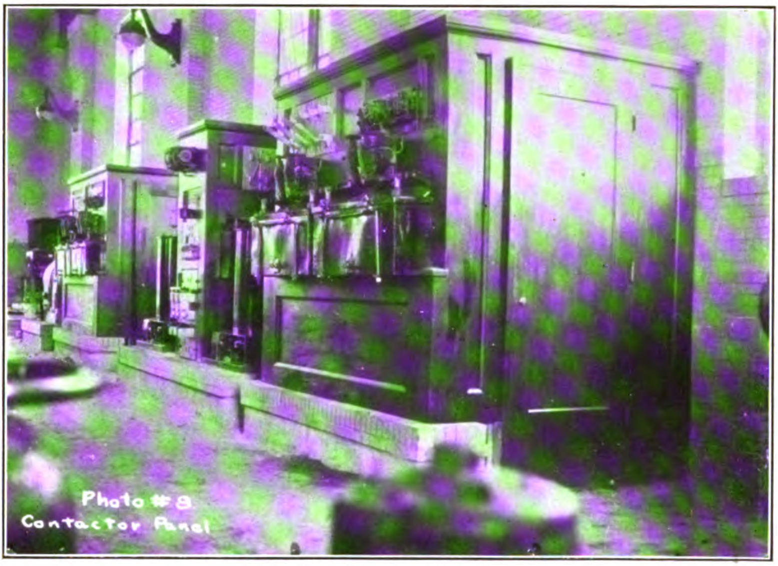


FIG. 9—CONTACTOR PANEL

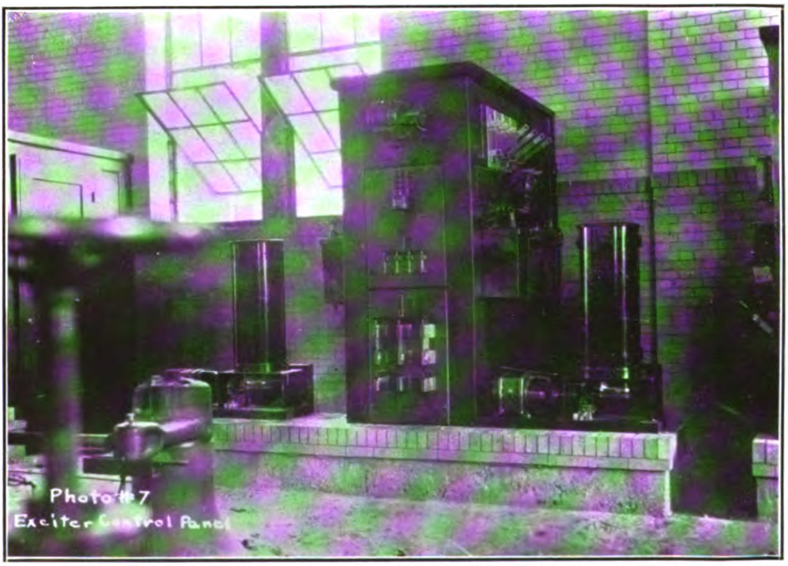


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FIG. 10—EXCITER CONTROL PANEL

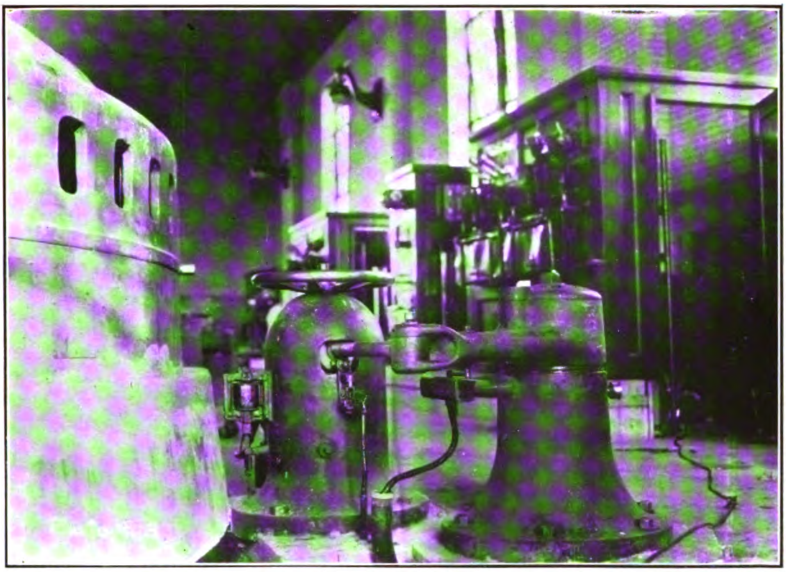


FIG. 11—GATE CONTROL

[DRABELLE AND BONNETT]

FIG. 12—REACTOR AND BUS

dicating ammeter (150 ampere scale) and wattmeter (600-kw. scale), there being no instruments in the hydroelectric plant. The leads for these meters from the current transformers in the hydroelectric plant are bunched in an eleven conductor, No. 4, lead-covered cable. These leads are wired through calibrating terminals at the hydroelectric plant so that portable meters can be wired in if desired at any time. The lower row of instruments on the benchboard is a totalizing equipment, reading the total incoming power from the hydroelectric plant. This consists of two ammeters, a power factor indicator, an indicating wattmeter, a curve-drawing wattmeter and a watthour meter.

The waterwheel gates are not supplied with the usual hydraulic governor; but instead the opening and closing of the gates is obtained by a 5 h. p. induction motor through suitable reduction gearing. The gear ratio is such that it requires 25 seconds for the gates to completely open, starting from rest in the closed position. The motor is equipped with a solenoid brake which releases when voltage is applied to the motor. This prevents overshooting by quickly stopping the motor after the power supply is interrupted. Each gate mechanism is equipped with a contact-making device operating indicating lamps on the benchboard at the Sixth Street station, showing the exact amount of gate opening.

The correct sequence of operations in the control of each generator is obtained by properly placed segments on the drum of a controller which is driven by a single-phase one h. p. repulsion-type motor. This controller definitely determines the proper time spacing between the different steps of starting the unit and connecting its generator to the bus. One of these is shown in Fig. 6.

The contactor equipment and protective relays are mounted in cabinets as shown in Figs. 7, 8 and 9. Fig. 8 shows the wiring back of the panels.

For controlling the exciter sets, two oil-immersed contactors are used, also a double-throw, triple-pole switch, which connects either one or the other of the exciters to the exciter bus. The middle blade of this switch selects the proper contactor for starting the exciter set which is connected to the excitation bus. This equipment is shown in Fig. 10. At the top of the cabinet will be noticed a small induction motor. This carries a centrifugal device on the end of the shaft which

in case of frequency of the system rises to 64 cycles, will open, and shut down the plant, thereby preventing runaway.

The units have individual float switches set for slightly different levels. If the water rises to a certain level it closes the float switch of the first unit, and that machine is started and put into service. If the flow of the river is such that the water continues to rise the second float switch closes, starting the second machine. The third switch is set still higher. The machines are shut down in the reverse order as the water level falls.

In general the sequence of operation of each generator is as follows: The closing of the float switch or the proper remote-control button in the steam station, starts the exciter set (provided it has not already been started with another generator), and opens the waterwheel gate. When the generator comes up nearly to synchronous speed it is connected to the bus without field but in series with a 20 per cent reactance. A weak field is then applied pulling the machine into synchronism. The field is then strengthened to full field, the reactance short circuited and the water wheel gates opened to carry full load on the unit.

The generators operate with a fixed excitation adjusted for normal full-load value. If the water level is so low that with full gate opening normal load cannot be obtained, the generator, due to its high excitation, takes care of part of the wattless kilovolt-amperes of the system. The speed and voltage are, of course, determined by the steam turbine generators.

Details of Operation

Detailed operation of this automatic equipment is as follows, referring to the wiring diagram:

Connected to the 2300-volt bus there are two small transformers stepping down to 220 volts, two-phase, for an operating bus. One phase is taken from this bus through the double pole switch No. 29, for controlling the contactors of each generator equipment. In the line between these transformers and the 220-volt bus there is an emergency throw-over switch which in case of failure of voltage on either phase is thrown over by a spring to a separate source of power brought in from the other station.

The closing of float switch No. 1, as shown on the right-hand side of the drawing, or control button No. 3 in the steam

station, closes contactor No. 4 provided that control button No. 2 is also closed. This energizes segment No. 14 of the controller. Segment No. 17 is in contact with its finger and a circuit is completed through the coil of contactor No. 6, which starts the motor driving the drum controller. A circuit is also made at No. 16 through the contacts of relay No. 41, which is not energized, through the coil of the contactor No. 5, through the contacts of relay *E*, the inverse-time relays No. 5 and the thermostat relay No. 10. The thermostat relay is connected across one phase of the control circuit and is of course, picked up if all the thermostats are closed, indicating that there is no overheating. Relay *E* is connected across the other phase and is picked up unless the frequency of the bus exceeds 64 cycles. Contactor No. 5 now closes energizing segment No. 1 of the controller. A circuit is now made through segment No. 2 picking up relay No. 42. Either one or the other of the two exciters sets can be started, depending on whether the switch *K* is closed up or down. The picking up of relay No. 42, completes the circuit through switches No. 28, which are closed, through the coil of contactor *G*, throwing full 2300 volts on the stator of the induction motor.

Contactor No. 43, with its coil across the armature of the exciter, short circuits with its contacts the field rheostat until the exciter voltage is built up to 75 or 80 volts. The set comes up to speed and the voltage up to normal very quickly and the d. c. voltage relay No. 11 picks up. The holding circuit of contactor No. 5 is now closed through this low voltage relay No. 11, the lower interlock of contactor No. 5 and through segment No. 15-A, so that No. 5 stays closed after No. 16 has left contact unless the exciter voltage drops.

In the meantime, the controller has been rotating and a circuit is made through finger No. 3 to the middle of point of relay No. 20. As the generator is not connected to the line there is no current flowing in the contact-making ammeter No. 21 and its contacts are closed in the up position. If No.1 button in the steam station is closed the left hand side of relay No. 20 is picked up. The energizing of finger No. 3, therefore, completes the circuit through the coil of contactor No.18-A, which starts the gate motor in the proper direction for opening the gate of the waterwheel. Finger No. 3 is in contact a definite length of time which is sufficient to give a gate opening on the waterwheel of such amount that the no-load constant speed would be about 65 or 70 rev. per min.

The controller motor has been receiving its energy through contact No. 6 held closed by finger No. 17. This finger next comes to the break in its segment and the controller stops in this position, waiting for the generator to come up to speed. On each generator there is a centrifugal device No. 13, set to close at about 55 rev. per min. that is, five rev. per min., below normal. When this switch closes, a connection is made from finger No. 17-A to No. 19 and through the controller to No. 18 to contactor No. 6, starting the controller again.

The gate opening is such that the generator is slowly rising in speed, so that by the time the segment No. 4 on the controller comes into contact, the speed is approximately normal. This segment closes contactor No. 23 connecting the generator to the bus without field and with a reactance in series. Finger No. 5 next closes the field contactor No. 24 putting a weak field on the generator and pulling it into synchronism. Finger No. 6 then closes contactor No. 40, short circuiting a part of the field rheostat, thus strengthening the field to full normal value. Finger No. 8 closes contactor No. 39, short circuiting the reactance. In the meantime finger No. 3 has come into contact again and the contact-making ammeter No. 21 opens the gate until the current of the generator is up to normal value.

The generator is now properly connected to the bus and carrying full load. Finger No. 17 comes to the second break in its segment and controller stops in the full running position.

The equipment can be shut down in several different ways. If the pond level falls, due to the fact that the demand for water is greater than the flow of the river; float switch No. 1 will open. If it is desired that the steam station shut down and start from the water level, button No. 4 will be open and the opening of both this button and the float switch will trip contactor No. 4. If it is desired to shut down any generator and prevent its starting again, button No. 2 in the steam station should be opened, thus also tripping contactor No. 4. This de-energizes segment No. 14 of the controller which in turn drops out contactor No. 5. This de-energizes segment No. 1 and drops out all other contactors connecting the machine to the bus. When contactor No. 5 drops out, the upper interlock makes a circuit through segments No. 19 and 18, picking up contactor No. 6 and running the controller to the off position. The middle interlock of contactor No. 5 is also closed, energizing contactor No. 18-B and closing the waterwheel gate. As

the controller rotates to the off position fingers No. 20 and 21 are bridged. These contactors are in parallel with the middle interlock on contactor No. 5 to give additional contact surface.

Connected to the operating bus in a one-h. p. two-phase motor driving a speed-limit device which opens its contacts when the speed exceeds 64 cycles. If for any reason, the hydroelectric plant becomes separated from the steam station, the generators will, of course, speed up increasing the frequency of the bus. This in turn will trip the speed limit device *D*, dropping out the four relays *E*, which in turn drop contactors No. 5 on all generators. This drops out all other contactors, and as the bus voltage then drops to zero the automatic throw-over switch No. 46 connects a separate source of power to the control bus thus furnishing energy for closing the gates of the water wheels to shut down. The wiring is so arranged that the relays *E* and No. 10 are connected outside this throw-over switch so that the generators cannot be started until the main cable between the station is re-energized.

If for any reason the generators have gone above speed and the main tie cable has been re-energized, relay No. 41 which is picked up whenever the centrifugal switch on the generator is closed, prevents the picking up of contactor No. 5, until the speed of the generator has dropped to a value somewhat below normal. This prevents the generator from being thrown on the line again when running at a considerable speed above normal.

The foregoing description covers only one generator; but also applies equally to the other generators. Each controller has a relay No. 42 so that the exciter can be started from any controller; that is, any generator can be started first and its controller starts the exciter.

The steam station is equipped with control buttons so that, if desired, the gate opening, and therefore the load on the hydroelectric generators, can be controlled from that place. The ammeter control is cut out by opening button No. 1,

Tests

A considerable number of tests were taken to determine what would happen in the automatic equipment in case of incorrect operation of the control buttons, or failure of some part to operate correctly.

First, one of the No. 1 control buttons was opened and the

load on the generator controlled by hand. It was found impossible to overload the generator, even with the gate opening to the full amount allowed by its limit switch. Button No. 1 was then closed, putting the ammeter again in control, and at the same time the operator tried to control the load from the gate control buttons. It was found that he could increase or decrease the load as desired; but when the hand control button was released the ammeter returned the load to the proper amount determined by its setting.

Buttons No. 2 and 3 were opened and immediately reclosed. The opening of these buttons tripped out all contactors and started the gate motor closing. The reclosing of the buttons caused the controller to rotate but since the generator was running at normal speed or a little above, relay No. 41 was held up and contactor No. 5 could, therefore, not pick up. This prevented any other contactors from closing. The controller made about one and one-half revolutions before the generator speed dropped so that relay No. 41 could reset. The next time around the controller picked up contactor No. 5, and went through the usual sequence of starting. This proved that if the operator accidentally opened one of these buttons and immediately closed it again, the generator would not be thrown immediately back on the bus, but would go through its proper sequence of operations.

In the steam station there is a voltmeter connected on the hydroelectric side of the oil switch. We next tripped this oil switch and found that the voltage dropped to zero in about two seconds, indicating that in this time the contactors in the hydroelectric plant had all tripped out, thus clearing the generators from the bus. Upon tripping of this oil switch the generators lost their load and tended to run away. Within the two seconds mentioned the speed limit device trips relay *E* at 64 cycles and all contactors drop out. The automatic throw-over control switch connects the separate source of power to the control bus and the dropping out of contactors No. 5 closes the water wheel gates. We did not read the maximum speed reached, but it was very apparent from watching the machines that the speed rose to not more than 20 to 25 per cent above normal. The action of the gate is quite rapid and the inertia of the machines is such that the gates closed before the wheels had time to accelerate seriously.

With the generator running under load we shut down the

exciter set. The armature current of the generator immediately increased in the contact making ammeter started to close the gate. The contactors connecting the generator to the bus dropped out, due to the tripping of the direct-current, low-voltage relay No. 11, which dropped because of the failure of the exciter voltage. The generator, after loss of field, broke from synchronism and tended to run above speed, but the contact-making ammeter had already closed the gate far enough to prevent serious overspeed, and the drop out of the contactors completed the closing.

Since the hydroelectric plant has been put into regular operation, the exciter in the main steam generator station failed one day. The load on the system, of course, was much greater than the hydroelectric plant could carry by itself, so that this plant should shut itself, down and clear from the steam plant. As soon as the exciter voltage in the steam station began to drop the current of the hydroelectric generators, of course, rapidly rose and the contact-making ammeters started the closing of the waterwheel gates. Before the voltage dropped too low, the ammeters had almost completed the closing of the gates. All contactors dropped out because of low voltage disconnecting the generators from the bus. The hydroelectric plant was ready to start again upon return of voltage on the tie cable between the two plants.

One of the accompanying illustrations shows an oscillogram taken of the starting conditions. This oscillogram is marked, showing the different contactors operated. The first part of the film shows the generator connected to the line without field. Next a weak field is applied, pulling the machine into step. The field is then strengthened to normal. There now seems to be a tendency for the current to pulsate, presumably caused by the heavy 20 per cent reactance in series with the machine. The short circuiting of this reactance quickly steadies the current into a stable condition. The wave shown at the end of the film is something less than normal load, as the contact-making ammeter, the day this film was taken, was set for holding less than full load. The time from the throwing on the line to the short-circuiting of the reactance is about eleven seconds.

Although the generators are slow speed and have considerable inertia, only 39 seconds are required from beginning of the opening of the gate until the generator is connected to the

bus, with a reactance short circuited. Within 45 seconds, the generator is carrying full load. In spite of the speed with which these generators are connected to the bus, there is no serious mechanical jar perceptible.

The plant has now been in operation from October 2nd until the present, and so far, no troubles, other than the small ones which always go with any new development, have been experienced, and these have all been of a very minor nature. The changes that have been made, consist essentially of substituting heavier and more reliable relays in one or two points on the control system, and the expectations and hopes of those who have worked on this development have been more than realized. The plant has successfully withstood short circuits exciter failures in the steam plant, low water and high water, and all of the tests that those in charge of the work could conceive of, wrong operations being brought about artificially. It has also been operated by the regular operating force at the steam plant, and there has been no occasion to keep men, nor have they been kept in the hydroelectric plant to watch its operation.

The automatic development, if it means anything at all, means that it will now be possible to develop a large number of small low head plants and tie them in on a high-tension system, leaving their operation entirely to the float switch and voltage relays. If there is voltage on all three phases of the high-tension line and water for the turbines, they will start up and go on the line without wrecking themselves or disturbing the operation of the rest of the system. In these days of scarcity of coal and scarcity of labor, together with its high price, the utilization of our water power is of national importance, for, every pound of coal that can be saved by the water of our rivers is just that much more that can be used by our country for the successful prosecution of the War.

With the elimination of the excessive labor cost of operation of a small plant, many water power sites are capable of development as a paying investment.

As this paper goes to press, the station has been in operation about seven months. Some notes as to experience with it might be of interest. During this time, the total flow of the river has been used at all times, and a toll of approximately 3,000,000 kw-hr. has been fed into the system. There have, of course, been a few failures to start, as no automatic apparatus can be

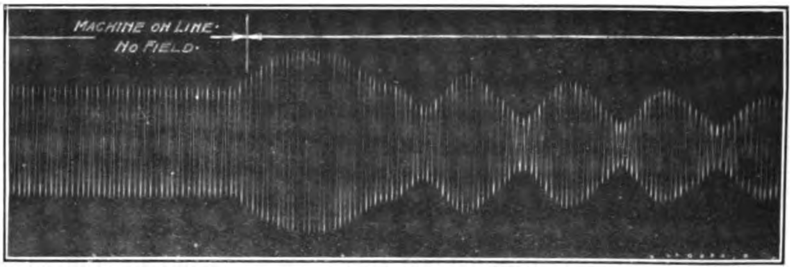


FIG. 14—GENERATOR ON LINE WITHOUT FIELD

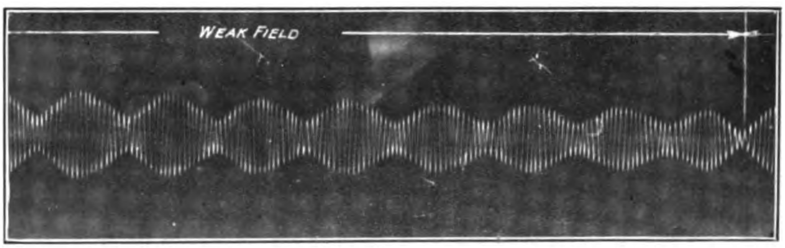
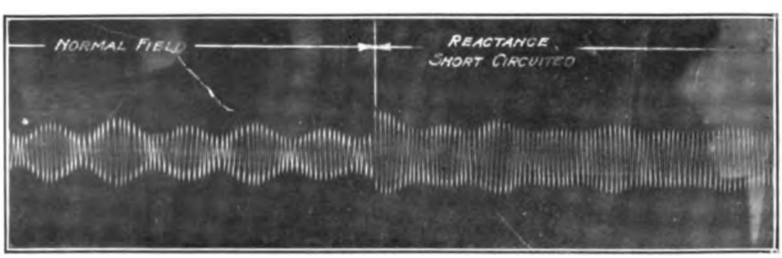


FIG. 15—GENERATOR WITH WEAK FIELD APPLIED



[DRABELLE AND BONNETT]

FIG. 16—GENERATOR WITH NORMAL FIELD

absolutely infallible. The source of such failures has been easily found and corrected. In this connection the equipment is designed to shut down in case of abnormal conditions, so that all the machines will be protected against injury. It is also of interest to note that owing to the pressure of other work and the shortage of help, this generat ng station ran continually for ten weeks, with no attention to automatic equipment of any kind. Of course, a more frequent inspection and cleaning of the contacts should be made in order to keep the equipment in the best of condition. There have been several cases of exciter trouble at the main steam station, which resulted in a complete shut down. As soon as bus voltage was restored, the automatic equipment put the hydroelectric plant back on the line without attention of any kind, and with no damage or injury to any of the machines. The expense for operators is a large per cent of the total cost of the operation of small hydroelectric plants. Many plants have considerable trouble in keeping their operating forces, particularly in these days of shortage of labor. With the present high price of coal and the shortage of labor, many small water powers might be developed with a profit as auxiliary plants on a fairly large steam generating system.

To be presented at the 34th Annual Convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 27, 1918.

PRE-CHARGED CONDENSERS IN SERIES AND IN PARALLEL

BY V. KARAPETOFF

ABSTRACT OF PAPER

A condenser is charged from a source of direct voltage, and then is used as a booster in series with this source to charge another condenser. By repeating this process a large number of times the second condenser is finally subjected to twice the voltage of the source. This is the principle of the Delon apparatus for testing cables, and is explained in a numerical example. Then the more general case of two or more "pre-charged" condensers in series is considered, when these condensers are connected to some source of direct voltage; it is shown how to determine the final distribution of voltages among them. A similar problem is solved for pre-charged condensers in parallel. Finally a general network of pre-charged condensers is considered, and equations are derived similar to Kirchoff's laws, from which the final distribution of voltages and charges may be computed knowing the initial distribution.

IN A paper presented before the Institution of Electrical Engineers (British) in February 1916, Mr. O. L. Record described Delon's apparatus for testing the insulation of a high-tension cable.[1] While endeavoring to make clear to himself the theory of this ingenious device the present writer has investigated in general the action of a pre-charged condenser used as a booster in series with some source of e.m.f. for charging another condenser. This led him further to deduce the equations of a general network of such condensers. Before giving these more general relationships it is of interest to explain the principle of Delon's apparatus in a simple numerical example.

The diagram of connections is shown in Fig. 1, in which C is a two-conductor cable under test, T is the testing transformer, R is a synchronous revolving rectifier arm, and C_1, C_2 are two "booster" condensers. The theory of the apparatus, confirmed by actual experience, shows that the cable is subjected to a continuous voltage which is numerically equal to twice the ampli-

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1. Journal Inst. Elec. Engrs. Vol. 54 (1916), p. 610; abstracted in the *Electrical World*, Vol. 67 (1916), p. 665.

tude of the transformer voltage. Thus a cable can be readily tested at quite a high voltage, without having a source of considerable reactive kilovolt-amperes, and without subjecting the cable to dielectric hysteresis or dangerous oscillations.

Theory of Delon's Apparatus. Let the capacities of condensers C_1 and C_2 each be equal to one quarter of that of cable C, and let the rectifying arm occupy the position shown in Fig. 1 at the instant when the lower terminal of the transformer is positive, and the voltage is at a maximum. Let the instantaneous value of this maximum voltage be 100 kilovolts and let the two condensers and the cable not be previously charged at all. Then at the instant under consideration condenser C_1 is subjected to the full potential difference of 100 kv. between points A_1 and B, and is being "pre-charged" for the next half of the cycle. For the sake of simplicity we shall assume that the duration of the contact is sufficient to charge C_1 to 100 kv.

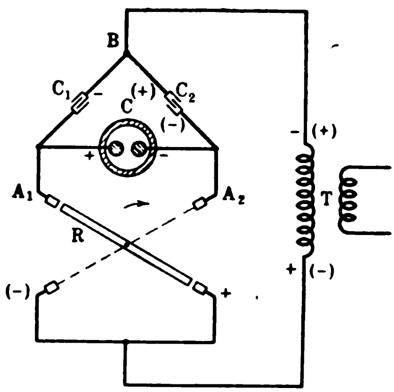

FIG. 1—DIAGRAM OF CONNECTIONS FOR TESTING TWO-CONDUCTOR CABLE

At the same instant the cable C is in series with condenser C_2 and the two together are subjected to 100 kv. Since the capacities C and C_2 are in the ratio of 4 to 1, the voltage across C is 20 kv., that across C_2 is 80 kv. It is important to note that the polarities marked at condensers C_1 and C_2 are those during the process of pre-charging. The polarity of C_2 during the first charge just described is opposite of that shown in the figure.

Half a cycle later the synchronous arm touches contact A_2 and the lower transformer terminal is negative. The corresponding polarities are shown in parentheses. The pre-charged condenser C_1 now serves as a booster in series with the transformer and helps to raise the charge on the cable, while condenser C_2 is being "pre-charged" between A_2 and B for the next impulse. We shall now determine the voltage to which the cable is charged after the second impulse.

Since the capacities C and C_1 are in the ratio of 4 to 1, any gain in voltage X across C corresponds to a loss of $4X$ across

C_1. In other words, if the new voltage across C is $(20 + X)$, that across C_1 is $(100 - 4X)$. But the total instantaneous voltage between A_2 and B is 100 kv., so that

$$(20 + X) - (100 - 4X) = 100,$$

from which $X = 36$ kv. Thus, after the second contact the cable is charged to 56 kv., while the original voltage across C_1 has dropped to -44 kv.

When the synchronous arm comes again in position A_1, the cable is connected in series with condenser C_2 which in the meanwhile has been charged to 100 kv. We thus have the equation

$$(56 + X) - (100 - 4X) = 100$$

from which $X = 28.8$ kv., so that the cable is now charged to 84.8 kv.

Carrying this reasoning further one readily finds that the voltage across the cable indefinitely approaches the value 200 kv. which is the double of the amplitude of the transformer voltage. Only after this value has been reached do the booster condensers and the transformer cease to charge the cable further. This is because the total voltage of the transformer plus that of a booster condenser is equal to 200 kv., and a permanent equilibrium is established. Let the cable voltage after the n – th charge be E_n. Then, by analogy with the foregoing expressions, we have for the $(n + 1)$ th application of voltage

$$(E_n + X) - (100 - 4X) = 100$$

or

$$X = (200 - E_n)/5 \qquad (\mathbf{1})$$

so that

$$E_{n+1} = E_n + X = 40 + 0.8\,E_n \qquad (\mathbf{2})$$

It will thus again be seen that the charging will stop or X will become zero when $E_n = 200$ kv.

Applying formula (**2**) to the first few charges (except the initial one) we get the following values:

20; 56; 84.8; 107.8; 126.3; 141; 152.8 kv.

Here the first value, 20 kv., does not satisfy the left-hand side of equation (**2**) when on the right-hand side one puts $E_n = 0$. However, it must be remembered that when the voltage is applied for the first time the booster condenser is not pre-charged so that equation (**1**) does not hold true either. Both equations hold true for every impulse except the first one.

One could imagine n condensers in place of each booster condenser, and with a proper commutating arrangement these

condensers could be pre-charged in parallel and discharged in series. In this case the cable could be subjected to a voltage equal to $n + 1$ times that of the amplitude of the transformer voltage. The idea of charging condensers in parallel and discharging them in series is not new and has been used for other purposes.

Two Condensers in Series. Let us now consider a more general case (Fig. 2) of a condenser of capacity C pre-charged to a voltage E_0 and of a booster condenser C' pre-charged to a voltage E_0'. Let the corresponding charges or displacements of electricity in the condensers be Q_0 and Q_0'. The operations will consist in charging C to a higher voltage by means of pre-charged C' in series with a battery e, then pre-charging C' again, raising the voltage of C, and so forth. The problem is to determine the consecutive values of the voltage across C. These values will be denoted by E_0, E_1, E_2, $\ldots . E_n$, while the corresponding pre-charge voltages of the booster condenser will be called E_0', E_1', $E_2' \ldots . E_n'$.

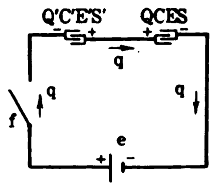

FIG. 2—TWO CONDENSERS IN SERIES

We have the fundamental relations

$$Q_0 = C E_0 \tag{3}$$

$$Q_0' = C' E_0' \tag{4}$$

Since the two condensers are connected in series, it is more convenient to use the reciprocal of capacity namely the so-called *elastance* of a condenser.[2] Introducing the elastances

$$\left. \begin{aligned} S &= 1/C \\ S' &= 1/C \end{aligned} \right\} \tag{5}$$

we get

$$\left. \begin{aligned} E_0 &= Q_0 S \\ E_0' &= Q_0' S' \end{aligned} \right\} \tag{6}$$

Let now condenser C' be connected in series with a constant-voltage battery e, and the switch f closed. With the polarities shown in the sketch the condenser C' assists the battery in further charging condenser C, and a quantity of electricity q

1. When a capacity is expressed in microfarads, the corresponding elastance is measured in mega-farads. See the author's "Electric Circuit" (McGraw-Hill, 1912), p. 148; also his paper "Sur quelques calculs pratiques des champs électrostatiques," *Trans. Congresso Internazionale delle Applicazioni Elettriche*, Torino, 1911.

is displaced through the circuit. The charge on C is increased to $(Q + q)$, that on C' is reduced to $(Q' - q)$. The corresponding voltages now are

$$E_1 = (Q_0 + q)\ S \tag{7}$$

$$E_1' = (Q_0' - q)\ S' \tag{8}$$

An equilibrium is established when

$$e + E_1' = E_1 \tag{9}$$

Substituting in this equation the values from equations (**6**), (**7**) and (**8**) we get

$$e + E_0' - q\ S' = E_0 + q\ S,$$

or

$$e + E_0' - E_0 = q\ (S + S') \tag{10}$$

so that

$$q = (e + E_0' - E_0)/(S + S') \tag{11}$$

All the quantities on the right hand side of this expression are known and q may be computed. Substituting this value of q in equation (**7**) we get

$$E_1 = E_0 + (e + E_0' - E_0)[S/(S + S')] \tag{12}$$

This expression permits one to determine the new voltage of condenser C knowing the initial voltages and the elastances of the condensers.

The larger the booster condenser the more it helps in charging the other condenser, but on the other hand the more expensive it is. Since the result depends only upon the ratio of the elastances we shall denote

$$S'/(S + S') = \alpha \tag{13}$$

$$S/(S + S') = 1 - \alpha \tag{14}$$

In the most efficient and most expensive case of an infinitely large auxiliary condenser ($S' = 0$) we have $\alpha = 0$. In the other extreme, when it is impossible to charge C because $C' = 0$ or $S' = \infty$, the ratio is $\alpha = 1$. In all cases α is a positive regular fraction, and may be called "slack factor." Equation (**12**) becomes

$$E_1 = (1 - \alpha)\ (e + E_0') + \alpha\ E_0 \tag{15}$$

or

$$E_1 = (1 - \alpha)\ V_1 + \alpha\ E_0 \tag{16}$$

Here

$$V_1 = e + E_0' \tag{17}$$

is the total charging voltage applied to condenser C at the instant of closing switch f.

Let now the switch be opened, the condenser C' pre-charged

to some other voltage E_1' and the switch closed again. By analogy with equation (**16**), the new voltage to which condenser C will be charged is

$$E_2 = (1 - \alpha)\ V_2 + \alpha E_1,$$

where $V_2 = e + E_1'$ is the new total charging voltage which in a general case may be different from V_1. If this charging process be repeated n times we get

$$\left.\begin{array}{l} E_1 = (1 - \alpha)\ V_1 + \alpha E_0 \\ E_2 = (1 - \alpha)\ V_2 + \alpha E_1 = (1 - \alpha)\ (V_2 + \alpha\ V_1) + \alpha^2 E_0 \\ E_3 = (1 - \alpha)\ V_3 + \alpha E_2 = (1 - \alpha)\ (V_3 + \alpha\ V_2 + \alpha^2\ V_1) \\ \qquad\qquad\qquad\qquad\qquad\qquad + \alpha^3 E_0 \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ E_n = (1 - \alpha)\ (V_n + \alpha\ V_{n-1} + \alpha^2\ V_{n-2} + \dots + \alpha^{n-1}\ V_1) \\ \qquad\qquad\qquad\qquad\qquad\qquad + \alpha^n E_0 \end{array}\right\} \quad (\mathbf{18})$$

No matter how many times the charging process be repeated the voltage across C remains finite because it cannot possibly exceed the highest charging voltage V applied to it.

In practise, the condenser C' would usually be pre-charged every time to the same constant value, say E', so that

$$V_1 = V_2 = \dots = V_n = V = e + E' \quad (\mathbf{19})$$

The preceding expression is then simplified to

$$E_n = (1 - \alpha)\ (e + E')\ (1 + \alpha + \alpha^2 + \dots + \alpha^{n-1}) + \alpha^n E_0$$

or

$$E_n = (1 - \alpha^n)\ V + \alpha^n E_0 \quad (\mathbf{20})$$

Compare this expression with equation (**16**). After an infinite number of applications of voltage, that is $n = \infty$,

$$\alpha^n = 0, \text{ and}$$

$$E_\infty = e + E' \quad (\mathbf{21})$$

independent of α or E_0. However, the values of α and E_0 determine the law according to which the voltage E approaches its ultimate value. With a small slack factor, α, that is with an expensive auxiliary condenser, the final value is practically reached after a few charges, while with an α near unity it may require many thousands of applications.

In the simplest case the same battery e would be used for pre-charging condenser C', so that $E' = e$. Equations (**20**) and (**21**) become

$$E_n = 2\,e\ (1 - \alpha^n) + \alpha^n E_0 \quad (\mathbf{22})$$

$$E_\infty = 2\,e \quad (\mathbf{23})$$

These two relationships apply in Delon apparatus.

Several Condensers in Series. We shall now consider a still more general case of several pre-charged condensers in series. Let the initial voltage, charge, and elastance of the k – th condenser be E_{k0}, Q_k and S_k respectively, so that originally

$$E_{k0} = Q_k S_k \tag{24}$$

Let all these condensers be connected in series and also in series with a source of constant voltage e, say a battery, and the switch closed. It is required to find the new voltages across the individual condensers.

We shall consider as positive those voltages E_{k0} which "buck" or oppose the battery voltage, while the voltages which help the battery will be considered negative. Let q be the displacement of electricity or the charge which passes through the circuit when the switch is closed. The new charge in the k – th condenser is $Q_k + q$, and the new voltage

$$E_{k1} = (Q_k + q)\, S_k = E_{k0} + q\, S_k \tag{25}$$

But when the equilibrium is established

$$\Sigma\, E_{k1} = e \tag{26}$$

or

$$\Sigma\, E_{k0} + q\, \Sigma\, S_k = e \tag{27}$$

Hence, the additional charge

$$q = (e - \Sigma\, E_{k0})/\Sigma S_k \tag{28}$$

But $e - \Sigma\, E_{k0}$ is the *net* voltage before the switch is closed, and $\Sigma\, S_k$ is the *equivalent* elastance of the whole circuit. We denote

$$e - \Sigma\, E_{k0} = e_n \tag{29}$$

$$\Sigma\, S_k = S_{eq} \tag{30}$$

The preceding expression for q becomes

$$q = e_n/S_{eq} \tag{31}$$

and the new voltage across the k – th condenser

$$E_{k1} = E_{k0} + e_n(S_k/S_{eq}.) \tag{32}$$

Condensers in Parallel. The case of several pre-charged condensers in parallel allows of a very simple solution. Let condensers of capacity C_1, $C_2 \ldots C_k \ldots C_n$ be pre-charged to voltages E_1, $E_2 \ldots E_k \ldots E_n$ respectively and then put in parallel. Let it be required to find the common voltage E after the equalization of the charges. The k – th condenser has lost voltage $E_k - E$, which means that it has lost a charge equal to $(E_k - E)$ C_k. But in the absence of a source of e.m.f. the sum of the

charges after the equalization is the same as before, so that the sum of the changes of charge must be zero. We thus have the equation

$$\Sigma\ (E_k - E)\ C_k = 0 \tag{33}$$

or

$$\Sigma\ E_k\ C_k - E\ \Sigma\ C_k = 0$$

from which

$$E = \Sigma\ E_k\ C_k / \Sigma\ C_k \tag{34}$$

When using this equation one has to be careful regarding the sign of each individual E_k. If all the positive terminals are connected together and all the negative ones together, then all the E_k's should enter in the equation with the same sign, say plus. But if some positive and other negative terminals are connected together, one should select a positive direction of e.m.f. and enter the individual E_k's in equation (**34**) with the sign plus or minus accordingly. As a practical application of pre-charged condensers in parallel the "method of mixtures" may be mentioned for measuring small capacities.[3]

Network of Condensers. As a most general case treated in this article, let a number of pre-charged condensers be connected in any arbitrary manner so as to form a network similar to a network of conductors. Let the initial voltage of the $k-$ th condenser be E_{k0}, the corresponding charge Q_{k0} and the elastance S_k, so that

$$E_{k0} = Q_{k0}\ S_k \tag{35}$$

Let various sources of d-c. voltage, e_1, e_2, e_3, etc. be distributed throughout the network. In the beginning a sufficient number of switches are supposed to be opened to prevent an equalization of charges and voltages. Then all these switches are closed, and it is required to find the new voltages and charges on the condensers.

The problem is solved in a manner similar to that in which currents are found in a complicated network of conductors, namely by applying equations analogous to Kirchoff's laws. As soon as the switches have been closed, the distribution of charges on the condensers changes, the $k-$ th condenser receiving an additional charge say q_k. Let q_k be considered positive when a positive displacement moves away from a junction point of three or more condensers. Since electricity behaves like an

3. See for example V. Karapetoff, Experimental Electrical Engineering, (Wiley) Vol. II, p. 9.

incompressible fluid, we have a relationship similar to the first Kirchoff law, namely

$$\Sigma\, q_k = 0 \tag{36}$$

An independent equation of this kind may be written for each junction point of the network but one.

For each dielectric circuit that can be traced within the network the second Kirchoff law may be applied which in this case simply becomes

$$\Sigma\, e = \Sigma\, E_{k1} = \Sigma\, (Q_{k0} + q_k)\, S_k.$$

But originally we had $Q_{k0}\, S_k = E_{k0}$, so that the preceding expression becomes

$$\Sigma\, e = \Sigma\, E_{k0} + \Sigma\, q_k\, S_k \tag{37}$$

A sufficient number of equations of this form can be written down, together with equations of the kind (**36**), to enable one to solve them as simultaneous equations for the unknown quantities q_k. Knowing a q_k, the corresponding new voltage across the condenser may be computed from the relationship

$$E_{k1} = (Q_{k0} + q_k)\, S_k = E_{k0} + q_k\, S_k \tag{38}$$

In the beginning the directions of q_k may be assumed arbitrarily; then those which actually take place in the opposite direction will come out negative, from the solution of equations (**36**) and (**37**).

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LIGHTNING ARRESTER SPARK GAPS

Their Relation to the Problem of Protecting Against Impulse Voltages

BY CHESTER T. ALLCUTT

ABSTRACT OF PAPER

This paper describes a new form of high-voltage lightning arrester gap which has been called the "impulse protective gap" because of its particular effectiveness in protecting against line disturbances of steep wave front.

The paper opens with a brief resumé of some of the results of previous investigations of the subject of impulse voltages. A discussion of the points involved in securing adequate protection against transient voltages of steep wave front follows. Particular reference is made to some of the conditions that may exist when a high-frequency impulse is superimposed on a low-frequency wave. In this connection is shown the desirability of a gap having a selective action, making it sensitive to steep wave fronts, and a number of forms of gap having this selective property are described.

Methods employed in testing these gaps are described and the results of a large number of experiments are tabulated. Tests on the action of a high-frequency impulse combined with a 60-cycle wave are included in the experimental work. From the experimental data a number of curves are plotted showing the discharge characteristics of the impulse protective gap under many different conditions.

The results of the tests are highly favorable and indicate that the new gap may have a wide application in the field of lightning protection.

IN GENERAL, a high-voltage lightning arrester consists of two distinct parts: First, a spark gap for discharging abnormal voltages; and second, means for preventing the normal line voltage from maintaining a power arc across the gap. In past years the satisfactory interruption of the power arc has been the most serious part of the lightning arrester problem, and, in consequence, the attention of manufacturers has been concentrated on the development of this feature. It is only comparatively recently that the gap itself has been receiving its due share of attention.

It is quite a simple matter to provide an electrical "safety valve" in the form of a spark gap to discharge abnormal voltages of low frequency, but when we have to deal with steep

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wave fronts, or impulse voltages, as they have been termed, there are certain complications due to dielectric spark lag. The existence of the phenomenon of dielectric spark lag was first brought to the attention of the Institute by E. E. F. Creighton[1] more than ten years ago. A later paper by Steinmetz and Hayden[2] gave the results of certain tests on the transient breakdown voltage of different gaps as a function of the energy available. Other papers[3] on impulse tests on porcelain shed some further light on the subject of dielectric spark lag but still left our knowledge of the subject in a rather incomplete state. It remained for F. W. Peek, Jr.[4] to present to the Institute the first quantitative data on the breakdown strength of different forms of gap under the action of transient voltages of carefully predetermined characteristics.

Mr. Peek's extensive investigations have definitely established the fact that some forms of spark gap require a very much higher voltage to discharge a high frequency impulse than is required to discharge a continuously applied e.m.f. The name "impulse ratio" has been given to the ratio of the impulse breakdown voltage of a gap to the continuously applied breakdown voltage. The impulse ratio was found to vary with the shape of the gap electrodes, the length of the gap and the shape of the impulse wave applied. In case of the needle gap, for example, the impulse ratio was found to be considerably greater than two under some conditions. The sphere gap, on the other hand, was found to have an impulse ratio of substantially unity through a wide range of gap setting. The general conclusion reached by Peek was that a gap in which the discharge is preceded by corona will, in general, have an impulse ratio greater than unity, the impulse ratio increasing with the nonuniformity of the field and with the steepness of the wave front applied.

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1. E. E. F. Creighton. Methods of Testing Electrical Porcelain. A. I. E. E. TRANSACTIONS, Vol. 25, p. 365, May 1906.

2. J. L. R. Hayden and C. P. Steinmetz. Disruptive Strength with Transient Voltages. A. I. E. E. TRANSACTIONS, Vol. 29, p. 1125, June, 1910.

3. A. Chernyschoff and C. A. Butman. Different Methods of Testing Electrical Porcelain. *Electric Journal*, Vol. 12, p. 282, 1915.

L. E. Imlay and P. H. Thomas. High Frequency Tests of Line Insulators. A. I. E. E. TRANSACTIONS, Vol. 31, p. 2233, December, 1912.

4. F. W. Peek, Jr. The Effect of Transient Voltages on Dielectrics. A. I. E. E. TRANSACTIONS, Vol. 34, p. 1695, September, 1915.

The relation of his experimental work on transient voltages to the subject of lightning protection was discussed by Peek in a later paper[5]. In this paper he indicates the desirability of a low impulse ratio in a lightning arrester gap and shows the superiority of the sphere gap as a protective device, over the simple horn gap usually employed in connection with high voltage arresters.

Protection Against Impulse Voltages

The papers referred to above have resulted in a great advance towards the solution of the problems involved in securing adequate protection against line disturbances of steep wave front. By the simple expedient of using a lightning arrester gap having spherical electrodes, the operating man may be perfectly sure that the voltage to ground at the point at which the arrester is installed will never appreciably exceed the 60-cycle discharge voltage of the gap. This is a great step in advance, but the question at once arises: Does it give the best possible protection against steep wave fronts? In this connection it must be pointed out that the danger to apparatus from an impulse voltage may be all out of proportion to the actual magnitude of the impulse. Consider, for example, a transformer winding designed for 50,000 volts. If 100,000 volts, at normal frequency, be applied to the winding the stresses on the insulation will only be doubled. But, on the other hand, if a high-frequency impulse of 100,000 volts be applied, the stresses on certain parts of the insulation may be many times normal because of the "piling up" of the steep wave front on the end turns of the winding. Consequently, if we are to protect the winding by means of a spark gap shunting it, the gap should be selective in its action; *i.e.*, it should discharge a high-frequency impulse at a *lower* voltage than an abnormal e.m.f. of line frequency.

The need for the selective action referred to above is emphasized by a consideration of the possible combinations of a high-frequency impulse with the normal line-voltage wave. Let us consider the three combinations shown in Fig. 1, and their effect on a winding protected by a gap.

Case A.—Impulse Occurring at Zero Point of Line E.M.F. Wave. In this case the presence of line voltage does not affect the action of the impulse. The insulation stresses in a winding

5. F. W. Peek, Jr. Lightning, *General Electric Review*, Vol. 19, p. 586, July, 1916.

and the discharge characteristics of a gap protecting the winding will be the same as if the impulse alone were applied.

Case B.—Impulse Occurring at the Peak of the Line E.M.F. Wave and Adding Thereto. In this case the total e.m.f. impressed on the gap and tending to discharge it is equal to the sum of the line voltage and the impulse voltage. The insulation stresses between turns of the winding, on the other hand, are largely dependent on the value of the impulse alone, since line frequency does not cause a high voltage between turns. It would appear that, in this case, the gap affords a better protection

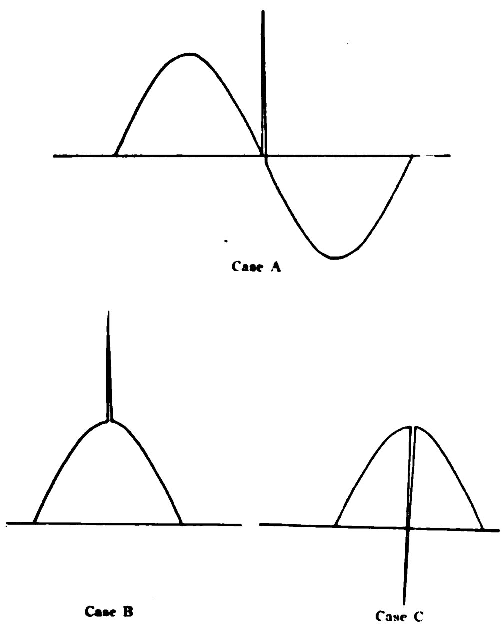

FIG. 1—IMPULSE VOLTAGES SUPERIMPOSED ON 60-CYCLE WAVES

than in Case A. For example, suppose the gap to be set at double line-voltage. In Case A, an impulse of double line-voltage may be impressed on the winding without the gap functioning, while in Case B the maximum impulse that can be applied to the winding without causing the gap to discharge is just equal to line voltage.

Case C.—Impulse Occurring at the Peak of the Line E.M.F. Wave and Subtracting Therefrom. In this case it is obvious that the gap furnishes much less effective protection than in the preceding two cases. A very considerable impulse voltage may

be impressed on the winding without causing any rise in voltage across the gap. The presence of the line-frequency wave prevents the impulse from causing a rise in voltage across the gap but does not prevent the full destructive effect of the impulse from being felt by the winding. Assuming, once more, that the gap is set at double line-voltage, it will be seen that an impulse of double line-voltage may be applied without causing any rise whatever in the voltage across the gap, while it will require an impulse of *three times* line-voltage to cause the gap to discharge.

The fact that such a condition is possible has not been generally appreciated, although it is clear that it may be a source of grave danger. Adequate protection against such a combination of high-frequency and line-frequency demands the use of a gap which is highly sensitive to steep wave fronts. It is true that, if the impulse is oscillatory, the second half-cycle may cause an ordinary gap to discharge, but such a discharge is too late to protect the winding against the destructive effects of the first half-cycle of the impulse.

The Impulse Protective Gap

A rather extensive experimental investigation of impulse phenomena has lead to the development of a new type of gap for lightning arrester service, which possesses in a marked degree the selective properties referred to in the preceding discussion. This gap has been termed the "impulse protective gap" because of its particular effectiveness in discharging line disturbances of steep wave front. The general principle underlying the action of the impulse gap is comparatively simple. In its most elementary form it consists of two gaps in series, each gap being shunted by a relatively high impedance. At line-frequency these impedances are proportional to the respective discharge voltages of the gaps which they shunt, but they are designed to change at different rates with changes of frequency so that, under the action of a high-frequency impulse, one of the impedances becomes much greater than the other and causes most of the high-frequency voltage to be impressed on one of the gaps. The breakdown of this gap will result in the total voltage being impressed on the remaining gap, which will break down in turn.

Fig. 2 is a diagrammatic representation of a gap constructed according to the above principle. One of the two equal gaps, g and g', is shunted by a condenser C' and the other by an equal

condenser C and an inductance L. At line-frequency, the inductive reactance of L is inappreciable compared with the condensive reactances and, therefore, causes no unbalance in the voltage across the two gaps. To a high-frequency impulse, however, the condensers offer very little impedance and most of the high-frequency voltage appears across the inductance L and thus across the gap g. Discharge of the gap g is, in general, immediately followed by a discharge across g'.

It has been found by experiment that better results are obtained by using a single gap, having an intermediate electrode, rather than two distinct gaps. Fig. 3 shows a number of different gaps constructed in this manner. *A* shows a horn gap having an auxiliary electrode mounted midway between the horns. The auxiliary electrode is connected to one of the horns through a condenser C' and to the other through a condenser C and an inductance L. The action is similar to that of the gap shown in Fig. 2.

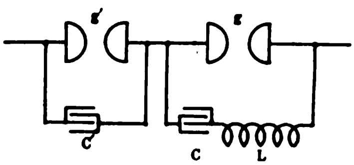

FIG. 2

In place of the reactance L, a resistance may be employed, as shown in Fig. 3B. This is the preferred form of gap, from a commercial standpoint, since the inductance used in *A* must necessarily be quite bulky, unless condensers of unreasonably high capacity be employed. With the structure shown in *B*, it has been found possible to secure excellent results with capacities as low as 10^{-11} farads.

Fig. 3C shows another form in which a reactance coil is used as an auto-transformer to produce a larger voltage between the auxiliary electrode and the main horn than is produced by the simple reactance shown in *A*.

Fig. 3D shows another modification, in which two intermediate electrodes are employed. R_1 is of greater resistance than R_2 so that a high-frequency impulse causes the right-hand gap to break down first, followed successively by the two others. For extremely long gaps it is probable that this form would give better results than *B*, but for commercial voltages it has been found possible to secure a gap of ample protective power by using but one auxiliary electrode.

Preliminary tests were made on a number of different gaps similar to those shown in Fig. 1. The early experiments included tests to determine the effect of different shapes of electrodes,

both for the main horns and for the auxiliary electrode. The results of these preliminary experiments indicated that the scheme shown in Fig. 3B was the most promising for commercial development. A wire of small diameter (practically a pointed electrode) was found to be most satisfactory for the auxiliary electrode. The pointed auxiliary electrode gave results so much superior to a spherical or cylindrical electrode that further experiment with these latter forms was dropped.

As a result of these preliminary experiments it was decided to make complete tests on the two forms shown in the illustrations, Fig. 4 and Fig. 5. These two gaps differed only in the shape of the horn electrodes. The gap shown in Fig. 4 had

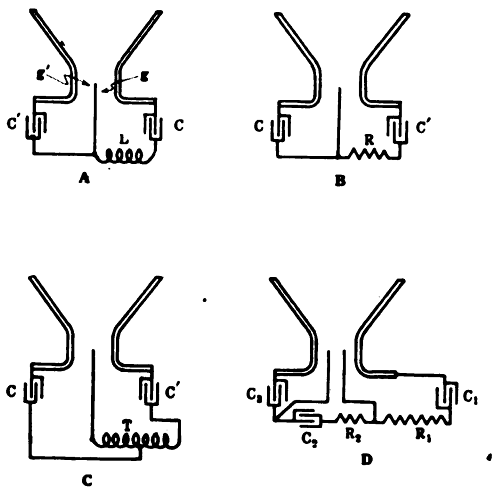

Fig. 3—Impulse Protective Gaps

plain horn electrodes made of 3 8-in. (0.95-cm.) diameter brass rod, while the other gap had brass hemispheres 6.25 cm. in diameter clamped to the horns, this presenting spherical discharge surfaces. In both gaps, the auxiliary electrode consisted of a blunt point of copper wire 0.025 in. (0.064 cm.) in diameter. During the tests, each horn was supported on a pillar insulator composed of three porcelain insulator units. These pillars rested on a wooden table which brought the gap to a height of about 5 ft. (1.5 m.) above ground. The porcelain units composing the pillars were of special design, having an unusually high electrostatic capacity, approximately 2×10^{-10} farads. Two of these units in series were used as the condensers between

the auxiliary electrode and each of the horns (corresponding to C and C' in Fig. 3B). A water tube was used for the resistance. In most of the tests its value was approximately 100,000 ohms.

TEST METHODS

The method employed in obtaining impulse voltages of predetermined characteristics was practically identical with that described by Peek in his 1915 paper.[6] Fig. 6 shows a diagram of connections. When the voltage of the transformer T is gradually raised, the sphere gap G_r will eventually discharge. At this instant, the condenser C is charged up to the breakdown voltage of the gap. When G_r breaks down, the condenser discharges through the inductance L and the resistance R. The wave form of this discharge current may be accurately calculated from the values of L, R and C. The shape of the voltage wave across R is, of course, identical with the shape of the current

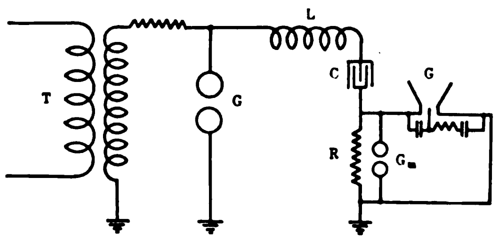

FIG. 6—CONNECTIONS FOR IMPULSE TESTS

wave. The gap G under test is connected across the resistance R. A sphere gap G_m is also connected across R in order to obtain a direct measurement of the impulse voltage. The voltage of the impulse applied to the gap under test may be varied by changing the setting of the gap G_r. For a more complete discussion of this method of obtaining impulses the reader is referred to Peek's paper.

The wave adopted as a standard for these tests was a critically damped impulse having a wave front corresponding to a 500,000-cycle sine wave. This wave is shown in Fig. 7. The constants of the oscillating circuit used in producing this impulse were approximately, $C = 10^{-9}$ farads, $L = 0.25$ millihenrys and $R = 1000$ ohms.

The procedure adopted in making the tests was as follows: First, the gap under test was adjusted to the desired setting.

6. Loc. cit. 4.

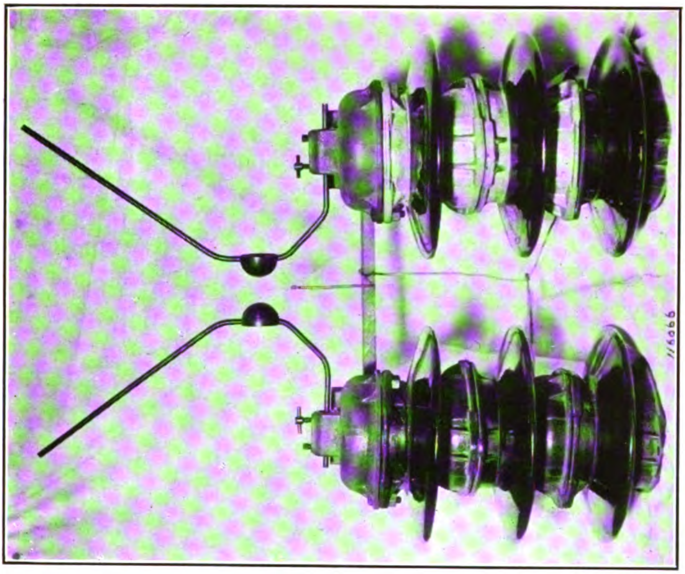

FIG. 5

[ALLCUTT]

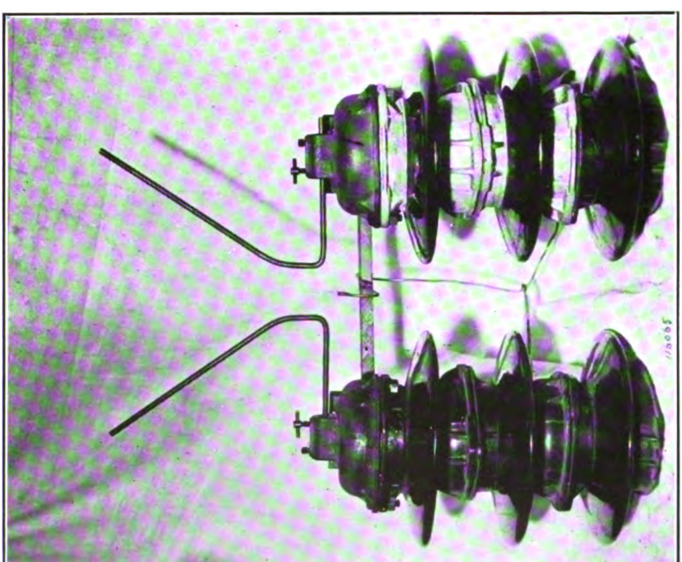

FIG. 4

Then successive impulses were applied at intervals of from 15 to 30 seconds and the gap G_r adjusted until a setting was found at which about 50 per cent of the impulses would discharge across the gap being tested. Then the measuring gap G_m was adjusted until the impulse discharges were shared equally by it and the gap under test. The setting of G_m that fulfilled this condition was taken as a measure of the impulse discharge voltage of G. Thus it will be seen that the impulse discharge voltage of the gap under test was in every case determined by direct comparison with a sphere gap.

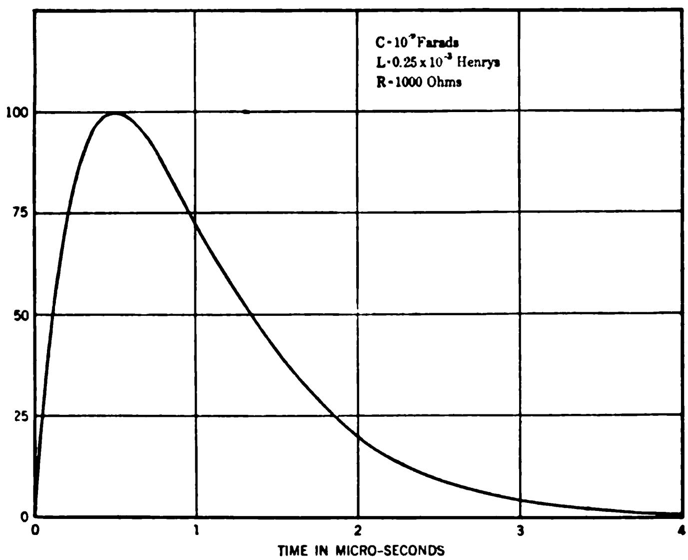

FIG. 7—500,000-CYCLE CRITICALLY DAMPED IMPULSE WAVE

The circuit used in testing the effect of an impulse voltage superimposed on a 60-cycle wave is shown in Fig. 8. Two high-tension transformers T_1 and T_2 are employed. These transformers are excited from the same 60-cycle supply circuit. T_1 applies a 60-cycle voltage to the gap while T_2 excites the impulse circuit which comprises a condenser C, an inductance L and a resistance R. As in Fig. 6, G_r is a spark gap used to regulate the impulse voltage. A condenser K of relatively large capacity is connected across the transformer T_1 external to the protective reactance L_p. This condenser presents a negligible impedance in comparison with the impedances shunting the gap G, so the

full value of an impulse voltage across the resistance R may be regarded as being impressed on the gap under test. If the voltage of the transformer T_2 be slowly raised, the impulse resulting from the discharge of G_r will occur at the peak of the 60-cycle wave. By proper selection of the relative polarities of T_1 and T_2 this impulse may be madeto add to, or subtract from, the 60-cycle wave produced by T_1, thus giving a resultant voltage wave, impressed on the gap G, similar to B or C in Fig. 1.

In making tests with the outfit described above, the voltage of T_1 was first set at the desired value. This voltage was carefully determined by means of a sphere gap, since the presence of the condenser K caused the terminal voltage of T_1 to be considerably above the value determined from transformer ratio. Then successive impulses were applied and, as before, a setting of G_r was found which would cause about 50% of the impulses

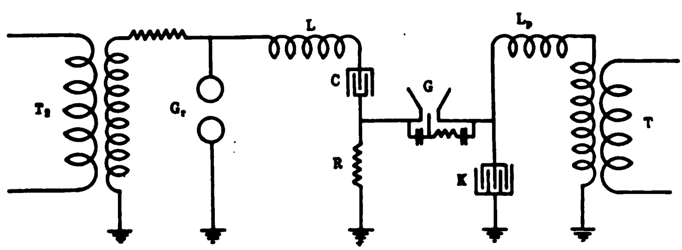

FIG. 8—CONNECTIONS FOR APPLYING IMPULSE VOLTAGE SUPERIMPOSED ON 60-CYCLE WAVE

to break down the Gap G. When testing the effect of the wave shown in Fig. 1B, where the impulse adds to the 60-cycle wave, the measuring gap G_m was connected in parallel with the gap under test and a direct comparison obtained between the two. In testing case G, where the impulse subtracts from the 60-cycle wave, the value of the impulse voltage was computed from the setting of G_r and checked by an occasional measurement with a sphere gap connected across the resistance R.

The 60-cycle discharge voltage of the gaps tested was determined in the usual way by comparison with a standard 25-cm. sphere gap.

RESULTS OF IMPULSE TESTS

The first series of experiments undertaken was for the purpose of determining the effect of the presence of the auxiliary electrode on the 60-cycle discharge voltage of the two forms of gap tested. Careful tests were made at gap settings ranging

from ½ in. (1.27 cm.) to 3 in. (7.6 cm.). The results of these tests indicated that the presence of the auxiliary electrode does not appreciably lower the 60-cycle discharge voltage. With the auxiliary electrode in place, breaks were somewhat less consistent

TABLE 1. IMPULSE PROTECTIVE GAP

3/8 in. Diameter Horn Electrodes.

Gap setting. inches	60-Cycle discharge. kv. max.	500,000 Impulse		Impulse ratio
		Discharge one side only kv. max.	Discharge both sides kv. max.	
0.5	37	16	16	0.45
1.0	60	28	28	0.47
1.5	73	40	40	0.55
2.0	81	53	55	0.68
2.5	88	67	73	0.83
3.0	93.5	80	84	0.90

than with the plain gap, but the irregularities were not of sufficient magnitude to indicate an appreciable lowering of the breakdown voltage.

Preliminary tests with impulse voltages were then made in

TABLE II. IMPULSE PROTECTIVE GAP

6.25 Cm. Spherical Electrodes Mounted on Horns.

Gap setting. inches	60-Cycle discharge. kv. max.	500,000 Impulse		Impulse ratio
		Discharge one side only kv. max.	Discharge both sides kv. max.	
0.5	39	12.5	12.5	0.31
1.0	71	30	30	0.42
1.5	99	47	49	0.50
2.0	121	60	65	0.54
2.5	137	74	82	0.60
3.0	147	85	93.5	0.64

order to determine the best values for the capacitances and resistances used in the circuits connecting the auxiliary electrode with each horn. The results of these experiments showed that the capacitances and resistances could be varied through wide

limits without affecting the impulse discharge voltage. The values of the capacitances employed in the succeeding experiments were, therefore, largely determined by convenience. In practically all the experiments discussed in the following pages, the condenser connected between the auxiliary electrode and each horn had a capacity of approximately 10^{-10} farads. As previously stated, each of these condensers consisted of two pillar-type porcelain insulator units in series (see Figs. 4 and 5). Using capacitances of the value given above, tests made with

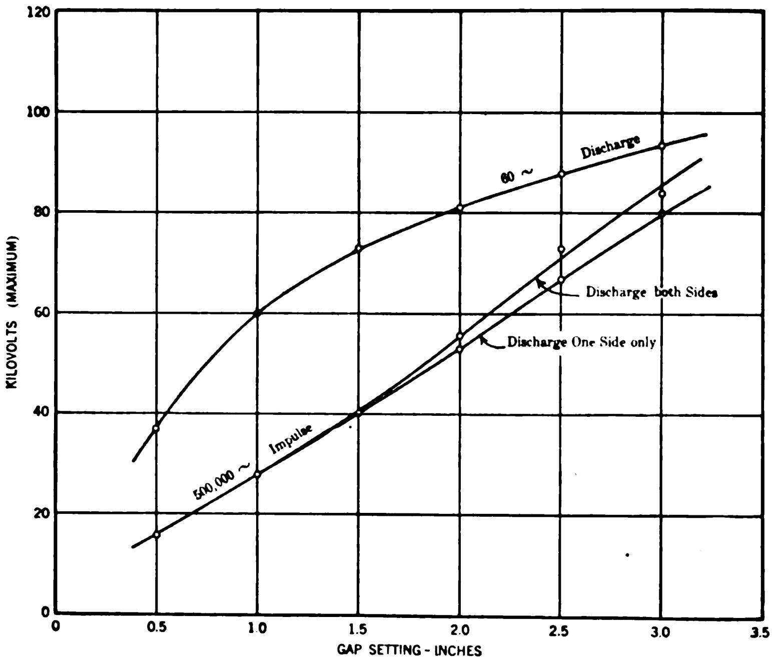

FIG. 9—DISCHARGE CURVES OF IMPULSE PROTECTIVE GAP ⅜-INCH DIAMETER HORN ELECTRODES

resistances varying from 50,000 ohms to several megohms showed no variation in the impulse discharge voltage of the gap. Accordingly, 100,000 ohms was selected as a convenient value of resistance to use in the remainder of the tests. This resistance is high enough to cause a very great unbalance in the voltage across the two sides of an impulse gap under the action of high frequency, and, on the other hand, is low enough to present a negligible impedance to 60-cycles in comparison with the capacitances employed.

Having decided on the constants given above, the two forms of impulse protective gap shown in Figs. 4 & 5 were tested for both 60-cycle breakdown and 500,000-cycle impulse breakdown, with various gap settings ranging from ½ in. (1.27 cm.) to 3 in. (7.6 cm.). The results of these tests are given in Tables I and II.

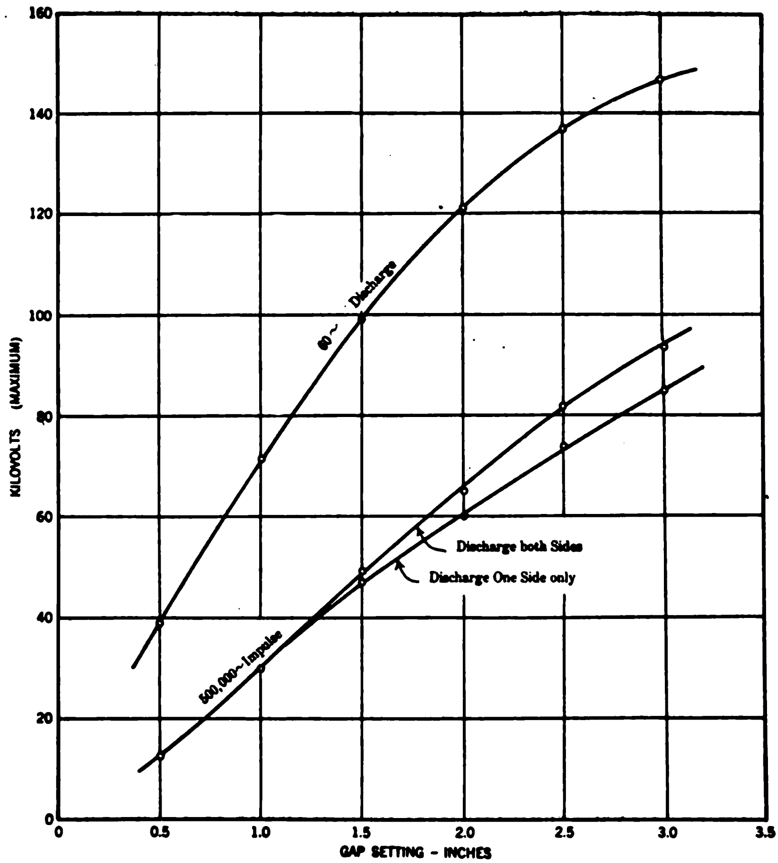

FIG. 10—DISCHARGE CURVES OF IMPULSE PROTECTIVE GAP 6.25 CM. SPHERICAL ELECTRODES MOUNTED ON HORNS

It will be noted that, under the heading "500,000 cycle impulse discharge voltage", there are two columns, one giving the impulse voltage which would discharge across one side of the gap only, and the other giving the impulse voltage required to cause a discharge across the whole gap. For small gap settings the difference between these two voltages was found to be too small

to measure; that is to say, successive applications of an impulse of just sufficient voltage to cause an occasional discharge, resulted in part of the discharges being across the whole gap and part of them being between the auxiliary electrode and one horn only. In computing the impulse ratio, given in column 5, the value of the impulse voltage required to discharge across both sides of the gap was used. This value of the impulse discharge voltage was also used in all the curves given hereafter except where the contrary is specifically stated.

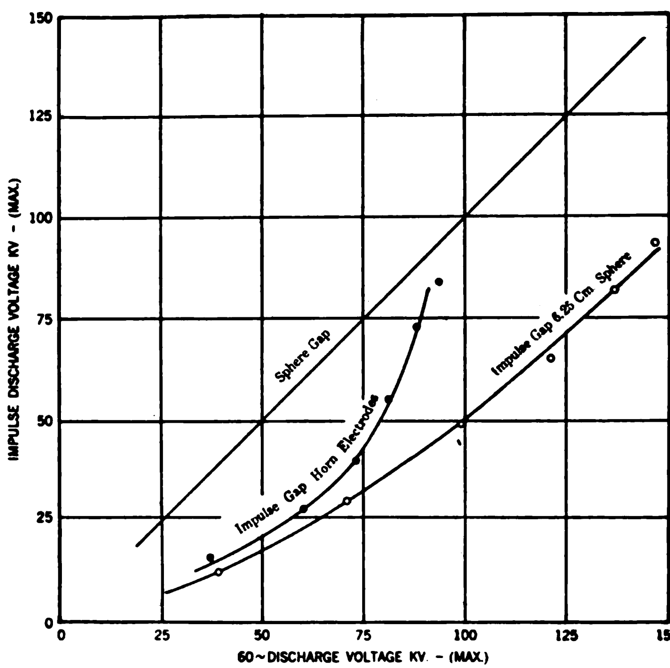

FIG. 11—CURVES SHOWING RELATION BETWEEN 60-CYCLE DISCHARGE VOLTAGE AND 500,000-CYCLE IMPULSE DISCHARGE VOLTAGE

The data given in Tables I and II are presented graphically in Figs. 9 to 12 inclusive. Figs. 9 and 10 give the 60-cycle and impulse discharge voltages as a function of gap setting for the two forms of gap shown in Figs. 4 and 5 respectively. It will be seen that in every case the impulse discharge voltage is *less* than the 60-cycle breakdown, indicating an impulse ratio of less than unity. In Fig. 11, the impulse discharge voltages are plotted against the 60-cycle discharge for the two forms of impulse gap

and for the plain sphere gap. Fig. 12 shows the impulse ratio of the two gaps as a function of gap setting. It will be noted that with the form of gap having the plain horn electrodes, the impulse ratio increases rapidly with the larger gap settings and will probably become higher than unity for gap settings much in excess of 3 in. (7.6 cm.). Where spherical electrodes are used, it is evident from the curves that the impulse ratio will remain well under unity even for gap settings considerably greater than 3 in. The reason for the superiority of the gap equipped with

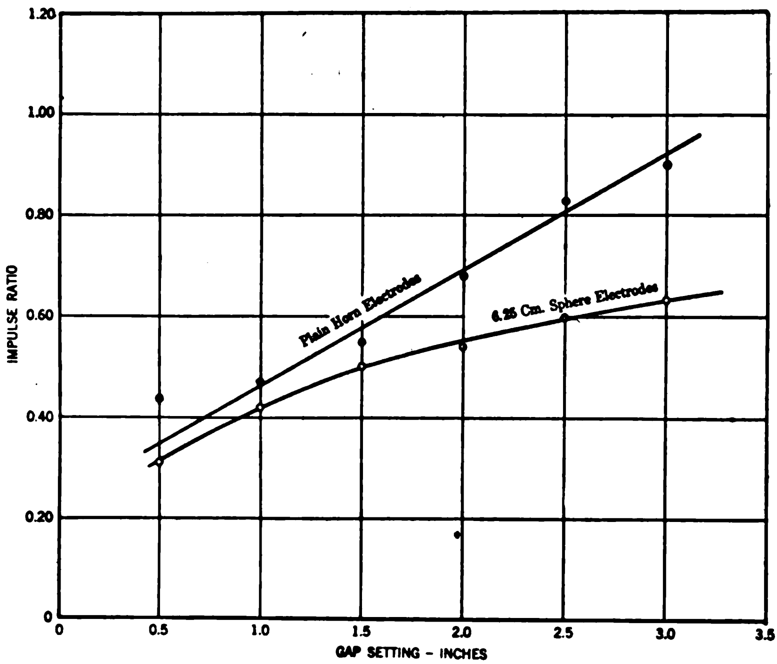

FIG. 12—IMPULSE PROTECTIVE GAPS—IMPULSE RATIO AS FUNCTION OF GAP SETTING

spherical electrodes may be made clear by reference to Figs. 9 and 10. By comparison of these curves it appears that, for a given gap setting, the impulse discharge voltages of the two gaps do not differ greatly. That is to say, a very great change in the shape of the main electrodes does not affect the impulse discharge voltage to a corresponding degree. We know, however, that the shape of the main electrodes will very mater ally modify the 60-cycle discharge. In view of these facts it is obvious that the lowest impulse ratio will be obtained by so shaping the main

electrodes as to give the highest possible 60-cycle breakdown voltage. This condition is approximated with spherical electrodes.

A consideration of the foregoing results seems to lead to the conclusion that the impulse gap has great possibilities as a protective device. In themselves, however, these results are by no means conclusive. The action of the new gap under more adverse conditions must be studied before its protective value can be regarded as definitely established. While it has already been shown that the impulse gap will discharge a much lower impulse voltage than a sphere gap having the same 60-cycle discharge, there remains the possibility that the gap may exhibit large time lag when an impulse considerably in excess of its discharge voltage is applied, thus permitting the voltage to rise to a dangerous value before discharge takes place. This condition was tested by determining the "equivalent sphere gap" of an impulse gap subjected to a transient voltage greater than its discharge voltage. The results of two series of tests made are

TABLE III. IMPULSE PROTECTIVE GAP

3/8 in. Diameter Horn Electrodes
Gap Setting, 1½ in. (3.8 cm.); 60-cycle Discharge 73 kv. max.

Impulse applied kv. max.	Equivalent Sphere gap	
	cm.	kv. max.
40	1.30	40
47	1.45	43.5
57	1.55	46
82	1.63	48
100	1 75	51

TABLE IV. IMPULSE PROTECTIVE GAP

6.25 Cm. Spherical Electrodes Mounted on Horns.
Gap Setting, 1 in. (2.54 cm.); 60-cycle Discharge, 71 kv. max.

Impulse applied kv. max.	Equivalent sphere gap	
	cm.	kv. max.
30	0.95	30
45	1.05	32.5
71	1.15	35
86	1.20	37
100	1.20	37

given in Tables III and IV and in the curves in Figs. 13 and 14. In obtaining the above results a sphere gap was connected in parallel with the impulse gap under test. Then a setting of the

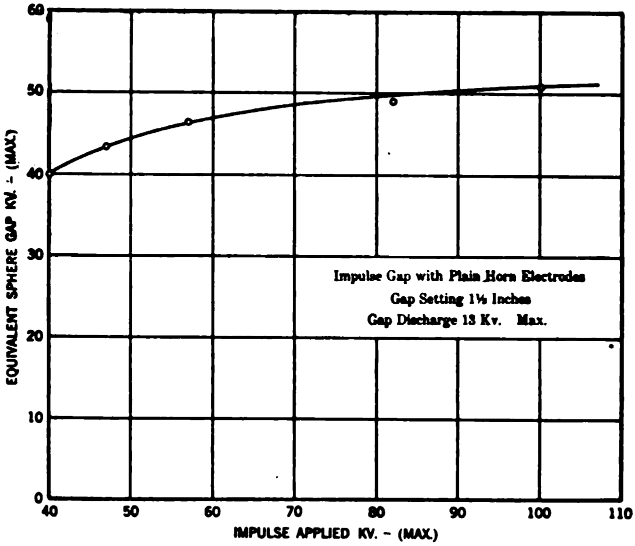

FIG. 13—SHOWING EFFECT OF IMPULSES HIGHER THAN THE IMPULSE DISCHARGE VOLTAGE OF THE GAP

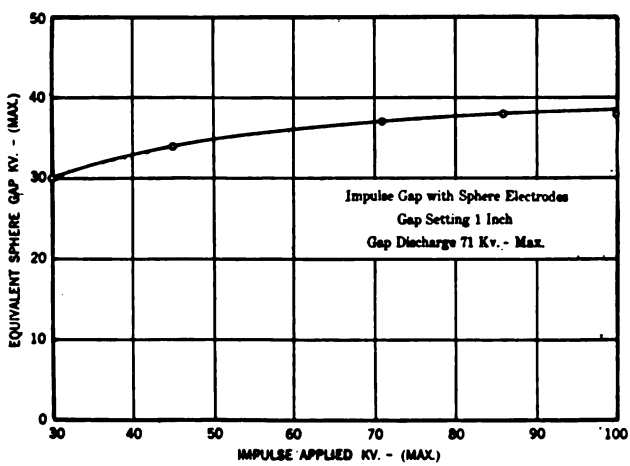

FIG. 14—SHOWING EFFECT OF IMPULSES HIGHER THAN THE IMPULSE DISCHARGE VOLTAGE OF THE GAP

sphere gap was found that would permit the two gaps to share the discharges equally when a given impulse voltage was applied. If we assume the time lag of the sphere gap to be negligible, this

"equivalent sphere gap" setting is a measure of the actual voltage to which the impulse gap permits an impulse of super-discharge voltage to rise. Figs. 13 and 14 show that the two forms of impulse gap do permit some rise in voltage above the minimum impulse discharge value, but this rise is not of sufficient magni-

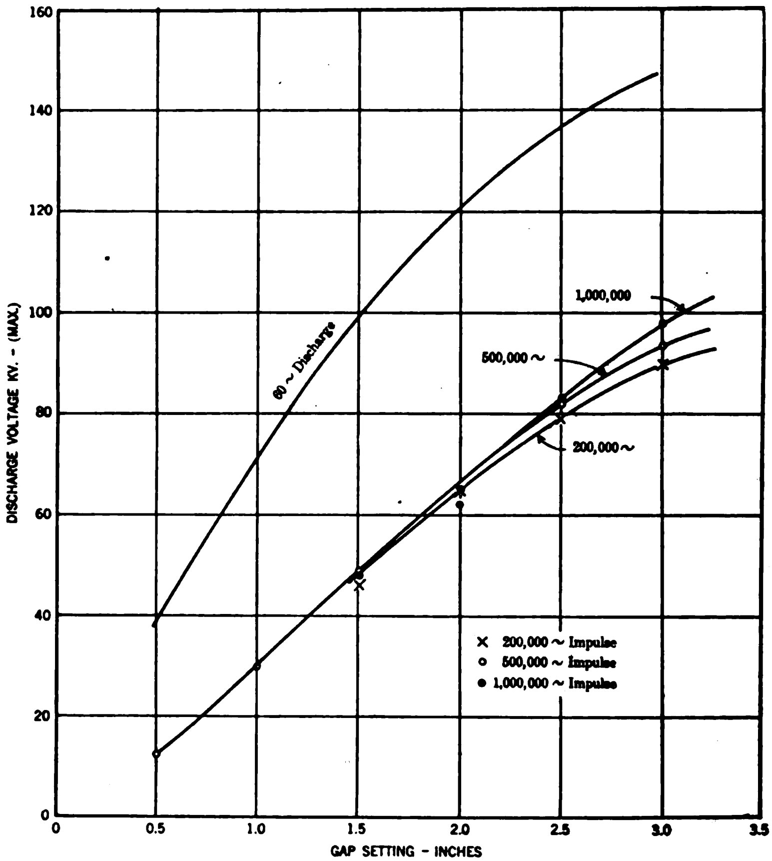

FIG. 15—TESTS ON IMPULSE PROTECTIVE GAP WITH SPHERE ELECTRODES SHOWING EFFECT OF IMPULSES OF DIFFERENT FREQUENCIES

tude to cut down seriously the degree of protection afforded. Even with an impulse applied, having a value of three times the minimum discharge voltage, breakdown occurs at very much less than the 60-cycle discharge voltage.

In addition to the above tests, it was thought desirable to undertake further experiments to determine the discharge char-

acteristics of the impulse gap with frequencies of other than 500,000 cycles. Fig. 15 shows the results of some of these tests. It will be seen that the impulse discharge voltage increases slightly with increasing steepness of wave front applied. This

TABLE V.

Impulse Protective Gap with [illegible]-in. diameter Horn Electrodes
Tests with 500,000 Impulse Superimposed on 60-Cycle Wave

Gap setting. Inches	60-Cycle discharge. kv. max.	60-cycle voltage applied. kv. max.	Impulse required to cause discharge		Equivalent line voltage kv. r. m. s.
			Case B kv. max.	Case C kv. max.	
1.0	60	30	9	30	36.5
1.5	73	36.5	16	45	44.5
2.0	81	40.5	20	52	49.5
2.5	88	44	40	71	54
3.0	93.5	47	41	90	57

increase in discharge voltage with increasing frequency is not very great, so it was not deemed necessary to make a complete series of tests at other than 500,000 cycles. It is a reasonable assumption that the tests made at this latter frequency will represent a fair average value of the discharge characteristics of

TABLE VI.

Impulse Protective Gap with 6.25 cm. Spherical Electrodes
Tests with 500,000 Impulse Superimposed on 60-Cycle Wave

Gap setting. Inches	60-cycle discharge. kv. max.	60-cycle voltage applied. kv. max.	Impulse required to cause discharge		Equivalent line voltage kv. r. m. s.
			Case B kv. max.	Case C kv. max.	
1.0	71	36	9	32	44
1.5	99	49.5	18	47	60.5
2.0	121	60	22	68	73.5
2.5	137	68	32	84	83
3.0	147	73	45	96	89

the gap under the action of high-frequency transients liable to occur in practice.

Results of Tests

Impulse Voltages Superimposed on 60-Cycle Wave

In making tests with an impulse voltage superimposed on a 60-cycle wave, the 60-cycle voltage applied was equal to one-half

the discharge voltage of the gap. With this 60-cycle voltage applied, the value of the impulse voltage required to cause discharge was determined both for an impulse adding to the 60-cycle wave and for an impulse subtracting therefrom. This test may be regarded as closely simulating conditions that may actually occur in practise. Having the gap set for a discharge voltage equal to double the 60-cycle voltage applied, was taken as a fair approximation of the usual practise with regard to the setting of lightning arrester gap.

The results of the tests made are given in Tables V and VI.

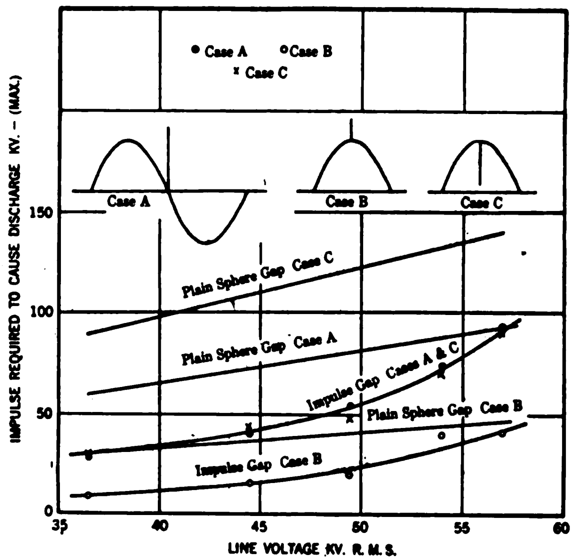

FIG. 16—TESTS ON IMPULSE PROTECTIVE GAP WITH PLAIN HORN ELECTRODES SHOWING EFFECT OF IMPULSES SUPERIMPOSED ON 60-CYCLE WAVE—GAP SET AT TWICE 60-CYCLE VOLTAGE TO GROUND

In column 3 are given the real peak values of the 60-cycle voltages applied at the different gap settings. This, is of course, equivalent to the peak value of voltage from one line to ground, which is applied to a lightning arrester gap in service. In order to form a more convenient basis for correlating the test results with service conditions, the root-mean-square value of the three-phase line voltage, equivalent to this peak voltage to ground, is given in the last column. Figs. 16 and 17 show, graphically, the impulse voltage required to cause discharge, as a function of this equivalent line voltage. The curves given for Case A are taken

from the results, given in Tables I and II, for the impulse voltage alone. It is interesting to note that, for both forms of impulse gap, the results for Cases A and C are practically identical. In addition to the curves for the impulse gaps, the characteristics of a plain sphere gap are shown for purpose of comparison. The curves for the sphere gap are computed, assuming an impulse ratio of one. It might be stated here that actual tests on a

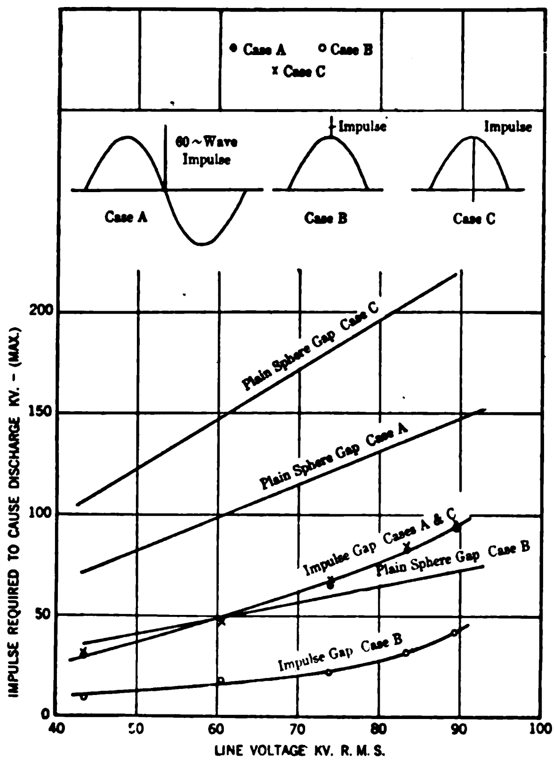

FIG. 17—TESTS ON IMPULSE PROTECTIVE GAP WITH SPHERICAL ELECTRODES SHOWING EFFECT OF IMPULSE VOLTAGE SUPERIMPOSED ON 60-CYCLE WAVE—GAP SET AT TWICE 60-CYCLE VOLTAGE TO GROUND

sphere gap subjected to an impulse subtracting from a 60-cycle wave (Case C) closely checked the computed curves given.

Figs. 16 and 17 are particularly effective in showing the very superior protection afforded by the impulse protective gap when subjected to an impulse subtracting from the 60-cycle wave (Case C). For example, on a 66,000-volt line an impulse protective gap would discharge such an impulse having a value of

but 56 kv. max. (See Fig. 16), while a plain sphere gap would require an impulse of 161 kv. max. to cause a discharge under the same conditions.

Conclusion

The conclusions arrived at from the foregoing experiments may be summarized as follows:

1. In order to secure adequate protection against line disturbances of steep wave front, it is important that a protective gap having the lowest possible impulse ratio be used. A gap having an impulse ratio of less than unity is particularly desirable.

2. There are certain combinations of a high-frequency impulse with a wave of line frequency for which the degree of protection afforded by an ordinary spark gap is greatly lessened. The need for a protective gap having selective properties, rendering it sensitive to steep wave fronts, is emphasized by these conditions.

3. A protective gap, having a selective discharge for steep impulses, may be constructed without greatly complicating the usual horn gap structure.

4. Exhaustive tests of such a gap have shown it to be superior to the ordinary sphere gap under all conditions. Even under the most unfavorable conditions the new gap gives a high degree of protection.


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PROCEEDINGS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS

Vol. XXXVII Number 6

JUNE, 1918

Annual Convention
Atlantic City, June 26-28
See Page 183, Sec. I.

PAPERS FOR THE ANNUAL CONVENTION

Eleven of the papers to be presented at the Annual Convention are Published in the May and June issues of the PROCEEDINGS. The four remaining papers will appear in the July PROCEEDINGS which will be published in advance of the Convention.

Reprints of all the papers will be available by June 15th.

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OF THE

American Institute of Electrical Engineers

Vol. XXXVII
Number 6

JUNE, 1918

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVII **JUNE, 1918** **Number 6**

A.I.E.E. ANNUAL CONVENTION

The Thirty-Fourth Annual Convention of the American Institute of Electrical Engineers will be held June 26-28, at Atlantic City, N. J. Institute headquarters will be at the Marlborough-Blenheim Hotel, where the technical sessions will be held. Members are requested to register promptly at headquarters which will open Wednesday morning at 9.00 o'clock for that purpose.

The convention will include six technical sessions, an informal reception and dance on the evening of the first day, and conferences of Institute officers and Section and Branch delegates at luncheon each day from 12:30 to 2:30 p.m. There has been no session assigned to Thursday afternoon in order that those present may avail themselves of the many attractions and entertainments which Atlantic City offers.

The convention will be opened by the Annual Address of President E. W. Rice, Jr., followed by the introduction of the President-Elect C. A. Adams, and the reports of the technical committees covering their work during the year, the advance in the state of the art and suggestions for future activities.

The Wednesday afternoon sessions will be devoted to papers relating to Transmission and Distribution problems. The subject of the Thursday morning session will be Protective Devices, and the Thursday evening session will be devoted to two subjects which have been made prominent on account of the war, namely, the supply of Nitrogen from the Atmosphere, and the Conservation of Fuel by Means of Utilization of Water Power. The sessions of Friday morning and Friday afternoon are devoted to papers on miscellaneous subjects of great importance.

PROGRAM

Wednesday, June 26

10:30 a. m.

President's Address, by E. W. Rice, Jr.

Introduction of the President-Elect, Prof. Comfort A. Adams.

Reports of Technical Committees.

12:30 to 2:30 p.m.

Conference of Institute Officers and Delegates of Sections and Branches at Luncheon

2:30 p.m.

Split-Conductor Cables—Balanced Protection, by William H. Cole, of the Edison Electric Illuminating Co. of Boston.

Aerial Cable Construction for Electric Power Transmission, by E. B. Meyer, of the Public Service Electric Co., Newark, N. J.

The Application of Theory and Practise to the Design of Transmission Line Insulators, by G. I. Gilchrest, of the Westinghouse Electric and Mfg. Co., Pittsburgh, Pa.

5:00 p.m.

Board of Directors' Meeting.

9:00 p.m.

Informal Reception and Dance.

Thursday, June 27

10:30 a.m.

Lightning Arrester Spark Gaps—Their Relation to the Problem of Protecting Against Impulse Voltages, by C. T. Allcutt, of the Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

The Oxide Film Lightning Arrester, by C. P. Steinmetz of the General Electric Co., Schenectady, N. Y.

The Oxide Film Lightning Arrester, by Crosby Field, Ordnance Dept., U. S. A.

Design of Transpositions for Parallel Telephone and Power Circuits, by H. S. Osborne, of the American Telephone & Telegraph Co., New York.

12:30 to 2:30 p.m.

Conference of Institute Officers and Delegates of Sections and Branches at Luncheon.

8:30 p.m.

Electric Power for Nitrogen Fixation, by E. Kilburn Scott, Consulting Engineer, London, Eng.

America's Power Supply, by C. P. Steinmetz, of the General Electric Co., Schenectady, N. Y.

Friday, June 28

10:30 a.m.

Pre-Charged Condensers in Series and in Parallel, by V. Karapetoff, of Cornell University, Ithaca, N. Y.

Method of Symmetrical Coordinates Applied to the Solution of Polyphase Net-works, by C. L. Fortescue, of the Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

Sustained Short-Circuit Phenomena, and Flux Distribution of Salient Pole Alternators, by N. S. Diamant, of Rice Institute, Houston, Tex.

12:30 to 2:30 p.m.

Conference of Institute Officers and Delegates of Sections and Branches at Luncheon.

2:30 p.m.

Reactance of Synchronous Machines and Its Application, by R. E. Doherty and O. E. Shirley, both of the General Electric Co., Schenectady, N. Y.

Protection from Flashing for D-C. Apparatus, by J. J. Linebaugh and J. L. Burnham, both of the General Electric Co., Schenectady, N. Y.

The Automatic Hydroelectric Plant, by J. M. Drabelle of the Iowa Railway & Light Co., Cedar Rapids, Ia., and L. B. Bonnett, of the General Electric Co., Schenectady, N. Y.

Entertainment

The Convention Committee has arranged for an informal Reception and Dance on Wednesday evening, June 26, at 8:30 p.m. and has also made arrangements whereby members who desire to play golf may obtain the privileges of the Atlantic City Country Club. Thursday afternoon has been reserved for games and other events, announcement which will be made by the Convention Committee in the final edition of the program to be distributed at the Convention.

The bathing and the other attractions at Atlantic City afford so much recreation that it has been deemed inadvisable to make any arrangements for entertainment other than those mentioned above.

Transportation

No special transportation rates are available and members should consult their local ticket agents regarding routes and rates. Parlor and sleeping car accommodations should be engaged in advance.

Hotel Reservations

Members should make their own reservations for hotel accommodations. As Atlantic City is generally crowded, members are advised to make reservations well in advance. The list given herewith contains the names, addresses and rates of several of the well known hotels in Atlantic City. The number of hotels is so large that lack of space prevents giving a complete list.

Hotel	Manager	Plan	Double rooms two persons		Single rooms one person	
			with bath	without bath	with bath	without bath
*Marlborough Blenheim	Josiah White & Sons Co.	American European	$12—$21 $ 9—$16	$12 $ 7	$8—$11 $6—$ 8	$6—$8 $4—$5
Brighton........		American	$13—$17	$11—$12	$8—$10	$6
Chalfonte.......	The Leeds Company	American	$12—$20	$10—$12	$9—$15	$6—$9
Chelsea.........	J. B. Thompson & Co.	American	$12—$16	$10—$12	$8	$6
Dennis.........	Walter J. Buzby	American	$11—$18	$9—$10	$7—$11	$5—$6
Haddon Hall....	Leeds and Lippincott	American	$11—$16	$9—$14	$7—$10	$5—$8
Shelburne.......	Jacob Weikel	European	$6	$5	$4	$3
St. Charles......	Newlin Haines Co.	American	$10—$13	$8—$9		$5
Strand..........		American	$12	$10	$7	$6
Traymore.......	J. W. Mott	American European	$10—$18 $ 6—$14		$9—$16 $5—$12	

*Institute headquarters.

REPORT OF COMMITTEE OF TELLERS ON ELECTION OF OFFICERS

To the President,
American Institute of Electrical Engineers.

Dear Sir:—This committee has carefully canvassed the ballots cast for officers for the year 1918-1919. The result is as follows:

Total number of ballot envelopes received	2256
Rejected on account of bearing no identifying name on outer envelope, according to Art. VI, Sec. 34, of the Constitution	28
Rejected on account of voter being in arrears for dues on May 1, 1918, as provided in the Constitution and by-laws	53
Rejected on account of ballot not being enclosed in inner envelope, or on account of inner envelope bearing an identifying name, according to Art. VI, Sec. 34, of the Constitution	56
Rejected on account of having reached the Secretary's office after May 1, according to Art. VI, Sec. 34, of the Constitution	21
	158
Leaving as valid ballots	2098

These 2098 valid ballots were counted and the result is shown as follows:

For President

Comfort A. Adams	2066
Scattering and blank	32

For Vice-Presidents

Harold Pender	2055
William B. Jackson	2051
John B. Taylor	2049
F. B. Jewett	2041
Allen H. Babcock	2036
Raymond S. Kelsch	2036
Scattering and blank	320

For Managers

Frank D. Newbury	1894
G. Faccioli	1760
Walter I. Slichter	1690
Morton G. Lloyd	554
Charles I. Burkholder	103
Scattering and blank	374

For Treasurer

George A. Hamilton	2038
Scattering and blank	60

Respectfully submitted,

LOUIS WINTNER, *Chairman*
F. V. MAGALHAES,
A. V. MERSHON,
G. E. SCHULTZ,
FRED P. WOODBURY,
Committee of Tellers.

DINNER TO PROFESSOR C. A. ADAMS

On Thursday evening, May 16, a dinner was given at the Engineers' Club, New York, in honor of Professor C. A. Adams, Chairman of the Standards Committee and President-Elect of the Institute for the administrative year beginning August 1, 1918. Those in attendance were members of the Standards Committee and the United States National Committee of the International Electrotechnical Commission, also the President and the Secretary of the Institute.

Dr. C. O. Mailloux was toastmaster; and there was a general discussion of the activities of the two committees referred to above and their relation to the development of the Institute. The occasion afforded an opportuni y or all present to felicitate Professor Adams upon his promotion to the presidency of the Institute and to pledge to him their hearty cooperation in the work of the coming year.

ANNUAL MEETING AND EDISON MEDAL PRESENTATION

The annual meeting of the A.I.E.E. was held at the Institute headquarters, 33 West 39th Street, New York, on May 17, 1918 at 8.30 p. m. The meeting was called to order by President E. W. Rice, Jr., who called upon Secretary Hutchinson to present the Annual Report of the Board of Directors. This report which was distributed at the meeting was briefly abstracted by Secretary Hutchinson. The report is published in full elsewhere in this issue.

The next order of business was the reading of the Report of the Committee of Tellers on Election of Officers for the administrative year beginning August 1, 1918. After this report, presented by Secretary Hutchinson and published elsewhere in this issue, President Rice announced the following as duly elected officers and managers: President, Comfort A. Adams Cambridge, Mass.; Vice-Presidents, William B. Jackson, Chicago, Ill., Harold Pender, Philadelphia, Pa., John B. Taylor, Schenectady, N. Y., F. B. Jewett, New York, Allan H. Babcock, San Francisco, Cal., Raymond S. Kelsch, Montreal, Canada; Managers, Frank D. Newbury, Pittsburgh, Pa., G. Faccioli, Pittsfield, Mass., Walter I. Slichter, New York; Treasurer, George A. Hamilton, Elizabeth, N. J.

President Rice then called upon President-elect Adams, who expressed the keen appreciation of the honor conferred upon him and the conviction that the most important function of the Institute for this year and until the war ends is to help to the utmost in the winning of the w r. Individu l and corporate interests must be sunk, and there must be the willingness to give freely, give "until it hurts." The big men must be brought to the fore, men big enough to know what co-operation means and also that co-operation must extend to every individual member of the Institute.

EDISON MEDAL PRESENTED

The ceremony of the presentation of the Edison Medal to Colonel John J. Carty, U. S. A., Chief Engineer of the American Telephone and Telegraph Company and Past-President of the A.I.E.E. for his work in the science and art of telephone engineering followed the business meeting. Dr. A. E. Kennelly as Chairman of the Edison Medal Committee outlined the origin and purpose of this honor and gave a brief history of past awards.

President Rice then called upon Dr.

Michael I. Pupin, Chairman of the Engineerng Foundation to tell something of the work of John J. Carty Dr. Pupin said in part, as follows: "Carty left the Latin School at Cambridge, at the age of eighteen and started work in the Bell system in 1879, and at twenty-eight, that is, in 1889, he became Chief Engineer of the New York Telephone Company. He started his scientific career without any academic trade marks and no degrees. Today he is a doctor many times over, and at the top of all his titles he is a Colonel in the U. S. A. General Pershing knows that Carty is the supreme commander of one of the best organized armies the world has ever seen—the army of the American Bell Telephone Company.

"The history of telephone engineering during the last forty years is a series of chapters created by his remarkable achievements in pure invention and constructive administration. He became Chief Engineer of the A. T. & T. Co. not because he is a great master, but because he is an untiring servant. He and many of his colleagues are wearing the uniform today, not as abadge of command, but as a badge of service."

President Rice referring to Colonel Carty as engineer, scientist, administrator, soldier and man, said that all those who knew him were only too glad to add their testimony as to his fine character and achievements. All were agreed that of the seven distinguished men who had received this signal honor the present medallist is a worthy companion. President Rice then presented the medal and certificate to Colonel Carty.

Colonel Carty in accepting the medal said that the credit which had been given to him should be shed over the the entire personnel of the Bell systems as whatever he had been able to accomplish had been due to the aid and assistance rendered by the men associated with him. He then went on to summarize what had been accomplished by the Bell system to aid in preparedness and the winning of the war all through the far-sighted efforts of his two superiors Mr. Bethell and Major-General Squier. He pointed out the severe tests to which the telephone system of the entire country had been subjected under simulated and actual war conditions and the forming of more than twelve battalions of the Signal Corps Reserve from the systems personnel some of whose officers accompanied General Pershing to France and all of whom have been doing splendid work over there.

President Rice before bringing the meeting to a close called on Dr. Bell who in a few brief remarks congratulated Colonel Carty upon the well earned medal he had received.

DIRECTORS' MEETING NEW YORK, MAY 17, 1918

The regular monthly meeting of the Board of Directors of the Institute was held at Institute headquarters New York, on May 17, 1918, at 3:30 p. m.

There were present: President, E. W. Rice, Jr., Schenectady, N. Y.; Vice-Presidents B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y.; Managers John B. Taylor, Schnectady, N. Y., Harold Pender, Philadelphia, Pa., C. E. Skinner, Charles M. Robbins and Wilfred Sykes, Pittsburgh, Pa., Walter A. Hall, Lynn, Mass., William A. Del Mar, New York, N. A. Carle, Newark, N. J.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $10,491.81 was ratified.

The following resolution, adopted at the meeting of the Board of Examiners held on May 6, was presented for the consideration of the Board of Directors with a request for instructions:

RESOLVED, that it is the sentiment of this board that enemy aliens should not be elected to membership in the Institute of Electrical Engineers pending the duration of the war.

The Board of Directors concurred in the view of the Board of Examiners that enemy aliens should not be elected to membership in the Institute during the period of the war and the Board of Examiners was instructed to defer action upon pending and future applications of enemy aliens.

Upon recommendation of the Board of Examiners the following action was taken upon pending applications:

63 Students were ordered enrolled.

127 Applicants were elected to the grade of Associate.

4 Applicants were re-elected to the grade of Associate.

10 Applicants were elected to the grade of Member.

1 Applicant was re-elected to the grade of Member.

1 Applicant was elected to the grade of Fellow.

3 Applicants were transferred to the grade of Fellow.

5 Applicants were transferred to the grade of Member.

Upon the recommendation of the Sections Committee the territory of the Denver Section was increased to a radius of 110 miles from Denver for the purpose of including Pueblo, Colo., Colorado Springs, Colo., Cheyenne, Wyo., and all other towns which may be located within this additional territory.

The annual Report of the Board of Directors for the fiscal year ending April 30, 1918, which had been prepared by the Secretary, was approved for presentation at the Annual Meeting in the evening. This report is published in this issue of the PROCEEDINGS.

Mr. F. L. Hutchinson was unanimously reappointed Secretary of the Institute for the administrative year beginning August 1, 1918.

Upon invitation of the American Institute of Architects, the President was authorized to appoint a representative of the Institute to attend a conference to be held in the Engineering Societies Building, New York, in June 1918, with the object of discussing the desirability of federating the building industry of the United States in order that the Government may have its cooperation and support.

A considerable amount of other business was transacted, reference to which will be found in this and future issues of the PROCEEDINGS.

COOPERATION WITH NAVY DEPARTMENT BY A.I.E.E. SUBCOMMITTEE ON WIRES AND CABLES

This Committee, which is a subcommittee of the Standards Committee, was appointed by the Institute at the request of Rear-Admiral Griffin, Chief of the Bureau of Steam Engineering to assist the Navy Department in the solution of problems relating to wires and cables, with special reference to the high-tension cables to be used on the new electrically-driven warships.

The Committee, after conducting a considerable amount of investigation and experimental research, sent reports to the Navy Department upon the following subjects. *Specifications for high-voltage cables on electrically-driven warships*; *Inductive interference of steel bulkheads when single-conductor alternating currents are used*; *Specification for varnished cambric insulation*; *Continuous carrying capacity of cables on warships; Intermittent carrying capacity of cables on warships*; *Use of grounding resistances for high-voltage cables on ships*; *Specification for rubber insulation*; *Use of reinforced rubber as a cable covering. Use of tape versus woven-wire armor.*

That the work of the Committee has proved of great value to the Navy Department is evident from the following letter received under date of April 22, 1918:

NAVY DEPARTMENT
Bureau of Steam Engineering
Washington, D. C.

April 22, 1918.

Gentlemen:

The Bureau has received report of your Committee of Jan. 30, 1918, supplemented to April 15th, covering recommendations and specifica-

tions for high-tension alternating-current generator and motor cables for main power circuits of electrically propelled warships. The result of this careful analysis of rather unusual problems, it is thought, will be of material assistance in their final solution.

It is with great pleasure that the Bureau extends to the American Institute of Electrical Engineers and to each individual member of its Subcommittee on Wires and Cables its sincere appreciation of the value of the work accomplished and its gratification at the generous and whole-hearted response given to the Bureau's request for cooperation.

Very respectfully,
(Signed) R. S. GRIFFIN,
Engineer in Chief, U. S. N.
Chief of Bureau.

American Institute of Electrical Engineers
Standards Committee,
Subcommittee on Wires and Cables,
Mr. W. A. Del Mar, Chairman,
33 West 39th Street, New York.

The Committee is still in conference with the Navy Department and expects to extend its activities to other departments of the Government.

NATONAL RESEARCH COUNCIL TO BE MADE PERMANENT BODY

EXECUTIVE ORDER

The National Research Council was organized in 1916 at the request of the President by the National Academy of Sciences, under its congressional charter as a measure of national preparedness. The work accomplished by the council in organizing research and in securing cooperation by milit.ry and civilian agencies in the solution o military problems demonstrates its capacity for larger service. The National Academy of Sciences is therefore requested to perpetuate the National Research Council, the duties of which shall be as follows:

1. In general, to stimulate research in the mathematical, physical and biological sciences and in the application of these sciences to engineering, agriculture, medicine, and other useful arts, with the object of increasing knowledge, of strengthening the national defense and of contributing in other ways to the public welfare.

2. To survey the larger possibilities of science, to formulate comprehensive projects of research, and to develop effective means of utilizing the scientific and technical resources of the country for dealing with these projects.

3. To promote cooperation in research, at home and abroad, in order to ecure concentration of effort, minimize duplication, and stimulate progress; but in all cooperative undertakings to give encouragement to individual initiative as fundamentally important to the advancement of science.

4. To serve as a means of bringing American and foreign investigators into active cooperation with the scientific and technical services of the War and Navy Departments and with those of the civil branches of the Government.

5. To direct the attention of scientific and technical investigators to the present importance of military and industrial problems in connection with the war, and to aid in the solution of these problems by organizing specific researches.

6. To gather and collate scientific and technical information at home and abroad, in cooperation with governmental and other agencies, and to render such information available to duly acc edited person.

Effective prosecution of the council's work requires the cordial collaboration of the scientific and technical branches of the Government, both military and civil. To this end representatives of the Government, upon the nomination of the National Academy of Sciences, will be designated by the President as members of the council, as heretofore, and the head of the departments immediately concerned will continue to cooperate in every way that may be required.

WOODROW WILSON.

THE WHITE HOUSE
11 May, 1918

MAJOR J. B. WHITEHEAD AWARDED EDWARD LONGSTRETH MEDAL OF MERIT

The Franklin Institute through the action of its Committee on Science and the Arts has awarded the Edward Longstreth Medal of Merit to Major J. B. Whitehead for his paper on "The Electric Strength of Air and Methods of Measuring High Voltage," appearing in the April 1917 issue of the *Journal of the Franklin Institute.*

In awarding this medal, the Committee adopted the following resolution:

RESOLVED, That the Edward Longstreth Medal of Merit be awarded to Dr. J. B. Whitehead for his paper entitled "The Electric Strength of Air and Methods of Measuring High Voltage" appearing in the April 1917 issue of the *Journal of the Franklin Institute*, a clear exposition of the underlying principles of the phenomenon of the electric corona at high potentials, a resume of the present methods of high-tension electrical measurement, and a full description of a new and noteworthy instrument—the Corona Voltmeter, invented by the writer—and its application to important problems in modern electrical engineering.

ENGINEERS' CLUB, PH LADELPHIA

At the Annual Meeting of the Engineers' Club of Philadelphia held May 21st, in the Club House, Mr. J. Franklin Stevens, a former Vice President of the Institute, was elected President of the Club.

The Engineers' Club of Philadelphia is the largest Engineers' Club in the country, having a membership of 2300. In addition to its regular membership it has affiliated with it the Local sections of the Institute and other national societies.

The Philadelphia Section of the Institute has for many years held its meetings and dinners at this club.

GOVERNMENT SERVICE

Officers Needed for Submarine Duty

U. S. Submarine Base: The Submarine Force of the United States Navy requires the services as officers on board of submarines, of young men who have had technical training in mechanical and electrical engineering and who have had experience in these professions. It is intended to enroll a number of such men as provisional Ensigns in the Naval Reserve Force, give them a course of instruction in deck duties at Annapolis and a course in submarine work at New London, Conn. Those who successfully pass these courses will then be sent on board of submarines for regular duty.

The qualifications required of the candidates are as follows:

1. A desire to serve in submarines.
2. A degree as mechanical engineer, electrical engineer, or mining engineer.
3. Two and one-half years practical experience in profession.
4. Not over thirty-five years of age.
5. Physically strong and sound in health.

The courses of instruction at the Submarine School require specialization in electricity, Diesel engines, torpedoes and submarine operation.

The Provost-Marshal General of the Army states that any person subject to the Selective Draft Law may be released therefrom to accept a commission in the U. S. Naval Reserve Force.

Members of the Institute or any other persons possessing the qualifications specified who desire to be considered as candidates, are requested to communicate at once with the Secretary of the Institute, Mr. F. L. Hutchinson, 33 West 39th St., New York, giving date and place of birth and a resume of their education and experience.

Naval Reserve Force: The Navy is in the most urgent need of 1,000 men, experienced in the operation and maintenance of gasolene engines. The men are required for immediate duty and will be rated as Machinists' Mates. Age limits 18 to 35. Applicants must be American citizens. Draft registrants with letters from their local boards will be accepted. Apply at Naval Reserve Enrolling Office, 51 Chambers St., New York, or at any Navy Recruiting Station.

A. I. E. E. HONOR ROLL

Members of the American Institute of Electrical Engineers in Army and Navy service with the United States and her Allies.

This list supplements those published in the last six numbers of the PROCEEDINGS and includes only those members who are in the armed forces and who have responded to the War Service card sent to the membership on Sept. 15, 1917, or have otherwise communicated with Institute headquarters.

Members in Army and Navy service who have not been listed are requested to furnish the Institute with their proper military designation.

ALLEN, ARTHUR E.
Lieutenant, Royal Flying Corps.

ARNETT, W. W.
328th Brigade Light Tanks.

BACON, FRANK R.
Major, Ordnance Dept.

DAWSON, C. A.
Second Lieutenant, Signal R. C.

DRUART, LEON OSCAR
Lieutenant, French Army.

DUNCAN, J. R.
Lieutenant, junior grade, U. S. N. R. F.

FEY, WM. L.
First Lieutenant, Engineer, R. C.

FLOWERS, ALAN E.
Captain, Signal R. C.

GAZDA, A. A.
Ensign, U. S. N. R. F.

GILBERT, JOHN J.
323rd Field Signal Battalion.

GILL, V. A.
31st Engineers.

GLEASON, R. R.
Ensign, U. S. N. R. F.

GOLDSMITH, CLARENCE
Major, Quartermasters' Corps, N. A.

GREEN, A. N. G.
Lieutenant, Canadian Engineers.

HAIG, WM. A.
2nd Engineer Training Regiment, Camp Humphres.

HATTEN, FRANK W.
Captain, Q. M. C., N. A.

HERSOM, FRED C.
Ensign, U. S. N. R. F.

HOWE, EDWARD S.
4th Officers Training Camp.

HUBBARD, H. V. S.
Lieutenant, Engineer, R. C.

HUSSEY, H. A.
Sergeant, Field Artillery.

INNES, FRANK R.
Medical Dept., Camp Merritt.

KEPHART, SAMUEL W.
Sergeant, Aviation Section, Signal Corps.

LEHNHOFF, RAYMOND G.
Sergeant, 308th Field Signal Battalion

LINDSEY, GEORGE H.
Machinist Mate, U. S. Navy.

MACKENZIE, A. M.
Lieutenant, Canadian Engineers.

MALONE, CLYDE A.
Major, Coast Artillery.

MANLEY, ROWLAND
Ordnance Dept., N. A.

McCUAIG, OLIVER B.
Sergeant, 2nd Field Co., Canadian Engineers.

McNAIR, JAMES S.
347th Field Artillery.

MONTCALM, S. R.
Radio Gunner, U. S. Navy.

OLDACRE, MARMION S.
National Army.

PARSONS, MORGAN
53rd Engineers, U. S. Army.

PRESTON, CHARLES R.
Cadet, School of Military Aeronautics.

ROOSEVELT, G. HALL
Aviation Section, Signal R. C.

RUGHEIMER, RALPH R.
U. S. Naval Training Station

SELTZER, DAVID
National Army.

SMALL, J. C. M.
Ensign, U. S. Navy.

STEVENS, A. M.
Lieutenant, senior grade, U. S. N. R. F.

WATSON, THOMAS S.
Major, Ordnance, R. C.

WEEKS, ROBERT W.
Lieutenant, Ordnance Dept.

WEILBACHER, WILLIAM C.
Engineer, U. S. Army.

WHIPPLE, CHARLES L.
Second Lieutenant, Signal Corps.

WICKERSHEIM, LYLE WM..
Aviation Section, Signal Corp.

WILLIAMS, J. F.
Lieutenant, U. S. N. R. F.

WRIGHT, CLYDE, F.
Second Lieutenant, Signal R. C.

SUMMARY OF MEN IN SERVICE

U. S. Army:

Brigadier Generals 2; Colonels 6; Lieutenant Colonels 4; Majors 62; Captains 143; First Lieutenants 161; Second Lieutenants 102; Sergeants 16; Corporals 7; enlisted men 130; miscellaneous 28. Total 661

U. S. Navy:

Lieutenant Commanders 9; Lieutenants 22; Lieutenants, junior grade, 76; Ensigns 19; enlisted men 14; miscellaneous 27. Total 167.

British and French Armies 15.

Grand Total 843.

COURSE IN RADIO COMMUNICATION

The University of Illinois offers a course in Radio Communication during the Summer Session of 1918, for men who wish to prepare themselves for research and development work or for field service in the Signal Corps of the Army. Instruction will begin Monday, June 17 and will continue until August 9. The assigned work will require the full time of the student registering. It it especially important that those who register should be well grounded in Physics and in Mathematics, including differential and integral calculus.

The physical and mathematical theories underlying the phenomena of radio telegraphy and radio telephony will be presented through lectures, recitations and experiments in the Radio Laboratory.

The following subjects will be studied: Sources of Energy for Radio Communication; Alternating-Current Circuits; Condenser Charge and Discharge; Hertz Oscillator; Systems of Radio Transmission; Influence of Surface of Earth, Weather and Other Factors on Radio Transmission; The Electron Discharge in Vacuum Tubes; Vacuum Tubes as Receivers, Amplifiers, and Transmitters; Arc and Tone Circuit Transmitters; Antennas for sending and for receiving; Airplane Radio Apparatus; Ground Telegraphy.

In addition to the theoretical work work mentioned above, the course will include practise in sending and receiving telegraphic messages in the International Morse Code.

The course is open only to citizens of the United States.

For further particulars regarding this course, apply to the Department of Electrical Engineering, University of Illinois, Urbana, Illinois.

PAST SECTION MEETINGS

Baltimore.—April 12, 1918, Johns Hopkins University. Paper: "Some Notes on Power Station Operation and Maintenance" by Alex E. Bauhan. Paper was illustrated by charts and lantern slides. Attendance 28.

May 10, 1918, Johns Hopkins University. Paper: "The Extension of Central Station Service with Special Reference to War Industries" by A. S. Loizeaux. Paper was illustrated by lantern slides. Attendance 15.

Boston.—April 30, 1918, Boston City Club. Ninth Annual Engineers Dinner under auspices of Boston Society of Civil Engineers, and A.S.M.E. and A.I.E.E. local sections. Mr. W. H. Blood gave an illustrated address on "Hog Island, the Greatest Ship Yard in the World", and Mr. Alfred D. Flinn spoke on "The Engineering Council, Its Progress and Aims". The meeting was also addressed by Mayor Andrew J. Peters of Boston, Major General Hodges of Camp Devens, and Mr. Westendarp. Attendance 250.

May 8, 1918, Engineers Club. Subject; "The Boston Section, Past, Present and Future. Speakers: E. W. Rice, Jr., President, A.I.E.E., and F. L. Hutchinson, Secretary, A.I.E.E. Annual election of officers as follows—chairman, Ira M. Cushing; vice-chairman, W. H. Timbie; secretary-treasurer, Ira M. Cushing. Attendance 35.

Chicago.—April 23, 1918, Western Society of Engineers Rooms. Paper: "The Automobile Power Plant" by C. F. Kettering. Brief address by Mr. H. E. Weightman on "Growing Crops by Electricity". Joint meeting with Chicago Section of A.S.M.E. Attendance 230.

Cleveland.—April 22, 1918, Statler Hotel, Electrical League Club Rooms. Address by Mr. R. K. Knowles on "Use of Storage Batteries in War." Attendance 38.

Denver.—April 16, 1918, Denver Athletic Club. Illustrated address by

Mr. E. R. Shepard on "The Work of the "Bureau of Standards". Attendance 20.

April 20, 1918, Denver Athletic Club. Papers: (1) "Electrical Development and Engineering Problems in the Orient" by C. B. Pierce; (2) "Wireless Telegraph and Telephones" by V. C. Flannigan; (3) "Electric Ship Propulsion" by P. A. Black; (4) "Electrical Engineering Possibilities in South America" by E. W. Develin; (5) "The University and the War" by C. M. Schloss. Attendance 70.

Detroit-Ann Arbor.—April 12, 1918, Detroit. Paper: "Hunting" by J. C. Parker. Attendance 50.

Ithaca.—March 29, 1918, Franklin Hall. Lecture by Prof. F. K. Richtmyer on "Illumination". Attendance 34.

April 26, 1918, Franklin Hall. Addresses as follows—(1) "Resuscitation from Electric Shock" by Prof. S. Simpson; (2) "Homopolar Generators" by Robert V. Morse; (3) "The Shucomor—A Device to Imitate the Operation of the Shunt Commutator Motor" by Prof. F. G. Switzer. Attendance 46.

Los Angeles.—April 9, 1918, Westminister Hotel. Paper: "Fuel Oil Conservation" by R. J. C. Wood. Attendance 25.

Madison.—April 16, 1918, Engineering Building. Paper: "Three-Phase Four-Wire Distribution" by G. E. Wagner. Attendance 19.

Milwaukee.—May 8, 1918, City Club. Illustrated addresses by Messrs. N. J. Whelan and V. S. Hillyer on "Wissota Dam". Attendance 75.

Minnesota.—April 10, 1918, University of Minnesota. Paper: "Methods of Increasing the Output of Hydroelectric Plants" by Daniel W. Mead. Attendance 150.

Panama.—February 22nd, 1918. Boat trip to Taboguilla Island, where luncheon was served and followed by entertainments. Attendance 107.

March 17, 1918, Balboa Heights, Canal Zone. Paper: "Design of Outdoor Substations" by W. T. O'Connell. Attendance 26.

April 21, 1918, Balboa Heights, Canal Zone. Paper: "General Notes on Methods Used in Public Utility Examinations" by E. A. Graham. Attendance 16.

Pittsburgh.—May 14, 1918, Chamber of Commerce. Paper: "Present Problems in Technical Education" by E. E. Sparks. Attendance 65.

Pittsfield.—April 11, 1918, Hotel Wendell. Lecture by Dr. Albert C. Crehore on "Modern Conceptions of Matter and Energy". Attendance 75.

April 25, 1918, Hotel Wendell. Illustrated lecture by Lieut. Colonel C. E. Brigham on "The Role of the Coast Artillery in the Present War."

Portland.—May 7, 1918, Multnomah Hotel. Paper: "Bureau of Standards and its Work with Special Reference to Electrolysis Mitigation" by E. R. Shepard. Attendance 38.

Rochester.—April 26, 1918, Rochester Engineering Society. Address by Mr. C. C. Carpenter on "The Design and Operating Characteristics of Storage Batteries". Attendance 40.

Salt Lake City.—March 20, 1918, Commercial Club. Paper: "Western Development and its Relation to National Transportation Policies" by John H. Lewis. Attendance 100.

San Francisco.—April 29, 1918, Engineers Club. Paper: "Electrolysis Mitigation and Other Public Work of the Bureau of Standards" by E. R. Shepard. Attendance 55.

Schenectady.—May 10, 1918, Edison Club Hall. Illustrated address by Mr. C. Francis Jenkins on "The Romance of Motion Pictures". Attendance 375.

Seattle.—April 16, 1918, Arctic Building. Paper: "Recent Additions to the Generating Equipment of the Puget Sound Traction, Light and Power Company" by S. C. Lindsay. Attendance 26.

Spokane.—April 19, 1918, W. W. P. Co. Building. Papers: (1) "Hydraulic Turbine" by C. F. Uhden; (2) "Test-

ing Hydraulic Turbines After Installation" by R. S. Daniels. Attendance 45.

St. Louis.—April 24, 1918, Engineers Club. Address by Mr. J. E. Allison on "Evaluation Work". Joint meeting with the Associated Engineering Societies of St. Louis. Attendance 46.

Toledo.—March 20, 1918, Builders Exchange. Illustrated lecture by Mr. H. M. Feathers on "Measuring Gas by Electricity". Attendance 30.

April 17, 1918, Scott High School. Illustrated lecture by Prof. E. E. F. Creighton on "The Theory and Practise of Lightning Protection". Joint meeting with Joint Section of Toledo Railways & Light Co.

Toronto.—April 19, 1918, Engineers Club. Paper: "High-Tension Insulators from the Operating Viewpoint" by Paul Ackerman. Attendance 35.

Utah.—April 19, 1918. Assembly Room, Commercial Club. Illustrated address by Mr. E. R. Shepard on "The Bureau of Standards and Its Work". Attendance 23.

PAST BRANCH MEETINGS

Bucknell University.—April 10, 1918. Paper: "High-Voltage D-C. Transmission in Europe" by W. E. Trimble. Attendance 7.

Colorado State Agricultural College.—April 23, 1918, Electrical Building. Demonstration of the oscillograph by Mr. R. E. Palmer. Attendance 10.

University of Colorado.—May 2, 1918, Engineering Building. Election of officers as follows: president, Albert S. Anderson; vice-president, Eugene L. Harlin; secretary, Terril C. Smith; treasurer, Thomas I. Matthews. Attendance 18.

Georgia School of Technology.—April 11, 1918, Chapel. Paper: "Opportunities for Technical Students" by S. A. Redding. Attendance 49.

April 25, 1918, Chapel. Address by Mr. A. M. Schoen on "War Work of the Engineering Societies." Motion picture "From Ore to Finished Pipe" by courtesy of National Tube Company. Attendance 71.

Kansas University.—April 18, 1918. Addresses as follows—(1) "Power Plant Tests" by W. T. Frier; (2) "Acceptance Test on 375-Kw. Turbo-Generator at Ottawa, Kansas" by Geo. M. Bowman. Attendance 18.

Massachusetts Institute of Technology.—May 13, 1918, Smith Hall. Illustrated address by Mr. Simon Lake on "The Answer to the Military Submarine." Election of officers as follows: president, Paul W. Blye; vice-president, William R. Maskay; secretary, Eugene R. McLaughlin; treasurer, Lloyd R. Sorenson. Attendance 107.

Michigan Agricultural College.—May 14, 1918. Address by Mr. Thomas on "The Uses of Electricity in the Iron Mines". Attendance 8.

University of Minnesota.—April 19, 1918. Paper: "Iron Wire Transmission Lines" by W. T. Ryan. Attendance 20.

University of Missouri.—April 22, 1918, Engineering Building. Paper: "Interference between Telephone and Power Lines" by R. E. Duffy. Attendance 24.

May 6, 1918, Engineering Building. Paper: "The Electric Propulsion of Ships" by C. W. Laughlin. Election of officers as follows—chairman, A. C. Lanier; vice chairman, C. W. Laughlin; secretary, D. P. Savant; corresponding secretary, B. J. George; asst. secretary, W. O. Virture; treasurer, G. B. Cox. Attendance 25.

University of North Dakota.—May 2, 1918, Mechanical Arts Building. Illustrated lecture by Mr. James L. Greene on "Lightning Arresters." Attendance 10.

Ohio Northern University.—May 2, 1918. Address by Prof. K. B. McEachron on "Telephone Engineering". Attendance 37.

May 6, 1918. Illustrated lecture on "Notes on Power Development" by A. J. Ferlic. Motion picture on "Romance of the Old Time School". Attendance 45.

May 14, 1918. Election of officers as follows—chairman, J. E. Summers; vice-chairman, O. Tavares; secretary, C. K. South; treasurer, H. D. Rouk. Attendance 27.

University of Oklahoma.—May 7, 1918, Engineering Building Paper: (1) "Automatic Electric Railway Substations" by B. F. Schultz; (2) "The Trend of Engineering Education" by T. W. W. Morrow. Election of officers as follows—chairman, A. E. Steedman; vice-chairman, J. H. Phillips; secretary, Paul Fahrney; treasurer, John Porter. Attendance 14.

Oregon Agricultural College.—May 8, 1918. Address by Captain W. D. Peaslee on "War Problems in the Trenches". Attendance 27.

University of Washington—April 9, 1918. Motion pictures on "Railway Electrification" by courtesy of Westinghouse Company. Attendance 60.

May 7, 1918, Forestry Hall. Address by Lieut. R. W. Shoemaker on "Engineering Practise". Attendance 12.

State College of Washington—May 10, 1918, Ferry Hall. Annual banquet. Election of officers as follows—chairman, Clarence E. Guse; vice-chairman H. L. Ziegler; secretary, Ralph C. Guse; treasurer, H. R. Zeuner; reporter, E. W. Tollefson. Attendance 26.

ASSOCIATES ELECTED MAY 17, 1918

AMBROSE, F. B., Republic Railway & Light Co., 1306 Mahoning Bank Bldg.; res., 609 Parkwood Ave., Youngstown, Ohio.

ANDRAE, GEORGE H. J., Industrial Heating, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 333 Barnes St., Wilkinsburg, Pa.

BALDWIN, J. C. B., Engineering Staff, The British Acetones; res., 24 Nanton Court, Nanton Ave., Toronto, Ont.

BARAGER, Chester A., Chief Engineer, Northern States Power Co., Montevideo, Minn.

BECKWITH, ARTHUR, Foreman, Otis Elevator Co.; res., 3504 7th Ave., Los Angeles, Cal.

BERRY, ALFRED FRANCIS, Commercial Engineer, The United Electric Light & Power Co., New York; res., 154 Sterling St., Brooklyn, N. Y.

*BIRD, FRANK STANLEY, Supt. of Construction, Nebraska Power Plant; res., Morris Apartments, Omaha, Neb.

BOECK, CHRISTIAN FREDERIC, Asst. Substation Operator, United Electric Light & Power Co., New York, N. Y.

BOWER, GEORGE WASHINGTON, District Chief Clerk, Public Service Electric Co., Camden, N. J.; res., Mechanicsville Road, Philadelphia, Pa.

BRADLEY, JOHN F., General Foreman, Underground Dept., The United Electri Light & Power Co.; res., 557 W. 174th St., New York, N. Y.

BRADT, ANDY W., Asst. Engineer, Hamilton Hydro-Electric System, City Hall; res., 49 Head St., Hamilton, Ontario.

BROOKS, LEWIS, General Foreman, Erie Works, General Electric Co.; res., 701 Payne Ave., Erie, Pa.

*CARTWRIGHT, KENNETH COLLWELL, Electrical Draftsman, U. S. Navy Yard, Norfolk; res., 1301 Morris Ave., Winona, Norfolk, Va.

CATCHING, W. R., Office Asst. to Supt., Pacific Gas & Electric Co.; res., 2824 Richmond Ave., Oakland, Cal.

CHESEBRO, HOWARD IRVING, Engineering Dept., United Electric Light & Power Co., New York; res., 953 E. 19th St., Brooklyn, N. Y.

CLAPP, PAUL SPENCER, Signal Corps, U. S. Army Radio Laboratories, Camp Alfred Vail, Little Silver, N. J.

CLARKE, HIRAM OPIE, JR., Commercial Manager, Houston Lighting & Power Co.; res., 1102 Clay Ave., Houston, Texas.

COOLEY, TALMAGE R., Sales Engineer, Cutler-Hammer Mfg. Co.; res., 172 16th St., Milwaukee, Wis.

CRAWFORD, ROBERT FOULTON, Electrician, Homestake Mining Co.; res., 415 S. Mill St., Lead, So. Dakota.

CUFF, PAUL S., Draftsman, General Electric Co.; res., 103 Nott Terrace, Schenectady, N. Y.

CURTIS, ALFRED STANLEY, Engineering Dept., Western Electric Co., 463 West St.; res., 11 E. 68th St., New York, N. Y.

DIAZ, ENRIQUE, Testing Dept., British Thomson-Houston Co.; res., "Belgrave", Clifton Road, Rugby, Eng.

DOYLE, GEORGE ALTAIR, Engineering Asst., Bell Tel. Co. of Pennsylvania; res., 5943 Osage Ave., W. Philadelphia, Pa.

DUSENBERY, H. SYRIL, Operating Dept., Pacific Gas & Electric Co.; res., 2232 Pacific Ave., San Francisco, Cal.

DWYER, WILLIAM O'BRIEN, Assistant Engineer, General Electric Co.; res., 327 South St., Pittsfield, Mass.

EATON, GEORGE OSCAR, Asst. Electrical Engineer, C. H. Tenney & Co., Boston; res., 50 Highland St., Marlboro, Mass.

EMERSON, CHARLES WESLEY, JR., Asst. Foreman, Meter & Test Depts., The United Electric Light & Power Co., 514 W. 147th St., New York, N. Y.

EMERSON, J. E., Sales Engineer, Canadian General Electric Co.; res., 94 Howard St., Toronto, Ont.

EVERETT, OLIVER STOCKBRIDGE, Switchboard Estimator, Condit Electrical Mfg. Co., So. Boston; res., 9 A Franklin St., Danvers, Mass.

FARNSWORTH, JAMES P., Junior Master, Teaching Electrical Course, Mechanic Arts High School, Boston; res., Arlington, Mass.

FRANDSEN, FRANK, Electrical Machinist, City Lighting Dept.; res., 7417 48th Ave. So., Seattle, Wash.

GALPIN, WILFRID DOUGLAS, Commercial Electrical Engineer, Foreign Dept., General Electrical Co.; res., 148 Elmer Ave., Schenectady, N. Y.

*GERMAIN, W. ADELBERT, Generator, Magneto & Ignition Expert, The Tom Botterill Automobile Co., Salt Lake City, Utah.

GILLILAN, PAUL MCVAY, Asst. Foreman, Testing Dept., General Electric Co.; res., 1 Harvard St., Schenectady, N. Y.

GOODES, ARTHUR WEBB, Chief Operator, Hydro-Electric Power Comm. of Ontario, Dundas; res., 19 Mount Royal Ave., Hamilton, Ont.

GORRY, EDWARD W., Chief of Operating Dept., The United Electric Light & Power Co.; res., 233 E.178th St., New York, N. Y.

GRASETT, COLIN SUTHERLAND, Asst. Construction Engineer, Hydro-Electric Power Comm.; res., 580 Spadina Ave., Toronto, Ont.

GROVE, ROBERT BRAGONIER, Asst. to Electrical Engineer, The United Electric Light & Power Co., 130 E. 15th St., New York; res., E. Orange, N. J.

HAILEY, ROBERT LEE, Electrical Engineer & Contractor, 90 West St., New York; res., 1639 E. 13th St., Brooklyn, N. Y.

HANENKAMP, GEORGE WILLIAM, Wireman & Switchboard Operator, The United Electric Light & Power Co.; res., 502 W. 180th St., New York, N. Y.

HARRISON, F. L., Foreman, Electrical Testing Dept., Hydro-Electric Power Comm. Laboratories, 8 Strachan Ave., Toronto, Ont.

HARVIE, HENRY, Chief Draftsman, Hydraulic Dept., Hydro-Electric Power Comm. of Ontario, 190 University Ave., Toronto, Ont.

HECKMAN, CHESTER L., Asst. Switchboard Engr., Westinghouse Elec. & Mfg. Co., Boston; res., 5-15 Braemore Road, Brookline, Mass.

HIETT, HENRY LEE, Division Foreman, Appalachian Power Co.; res., Byllesby, Va.

HILTZ, GEORGE S., Supt., Stock Quotation Telegraph Co., 26-28 Beaver St., New York; res., 213 E. 3rd St., Brooklyn, N. Y.

HORIMURA, HIROSH, Student Engineer, General Electric Co., Schenectady; res., 237 Riverside Ave., Scotia, N. Y.

HOUTS, GUY JOSEPH, Chief Draftsman, Equipment Engg. Dept., Western Electric Co. Inc., Chicago; res., 1118 Clinton Ave., Oak Park, Ill.

HOY, GEORGE ALBERT, Instructor, Dept. of Electrical Engineering, Univ. of Pennsylvania, Philadelphia, Pa.

IVES, JOHN NASH, Electrical Engineering Dept., Lockwood, Greene & Co., Boston; res., West Medway, Mass.

JACOBSON, CONRAD, Foreman, American Nitrogen Products Co., Le Grande, Wash.

JACOBSON, OLOF H., Asst. to Construction Engineer, The Mountain States Tel. & Tel. Co.; res., 456 Ogden St., Denver, Colo.

JEWETT, JOHN M., Salesman, Western Electric Co., Richmond; res., Ivanhoe, Va.

*JOYCE, HARRY B., Power Engineer, The United Electric Light & Power Co., New York; res., 81 Columbia Heights, Brooklyn, N. Y.

KANE, THEODORE FRELINGHYSON, Operator, City Light Dept.; res., 5121 Mead St., Seattle, Wash.

KELLEY, STANLEIGH ORMOND, Power Rep. & Sales Engineer, Public Service Electric Co., 418 Federal St., Camden; res., Woodbury, N. J.

KILPATRICK, ARTHUR SYDNEY, Construction Supt., C. H. Tenney & Co., 201 Devonshire St., Boston; res., Norfolk, Mass.

KIMBALL, JOHN T., Asst. Electrical Engineer, Wisconsin Railroad Commission; res., 916 E. Gorham St., Madison, Wis.

LAMSON, HORATIO WELLINGTON, Radio Expert, Radio Laboratory, U. S. Navy Yard, Boston; res., 83 Brattle St., Cambridge, Mass.

LAWRENCE, B. F., Service Engineer, Westinghouse Elec. & Mfg. Co., 214 North 22nd St., Philadelphia, Pa.

LEACOCK, GEORGE D. Y., Sales Manager, Moloney Electric Co. of Canada, Ltd.; res., 14 South Drive, Toronto, Ont.

LEWIS, WILLIAM, Construction Engineer, Bethlehem Steel Co., Felton, Cuba.

LYLE, GORDON HOLMES, Tabulator, Accounting Dept., Panama Canal, Balboa Heights, C. Z.; res., Ballston, Va.

LYNCH, FRED A., Asst. Electrical Engineer, Pennsylvania Shipbuilding Co., Gloucester; res., 33 N. 34th St., Camden, N. J.

MACNEILL, HENRY THOMAS, Chief Operator, Miraflores Power Plant, Miraflores; res., Ancon, C. Z.

MAIN, W. R., Construction Foreman, (Electrical) Public Service Electric Co.; res., 36 N. Broad St., Burlington, N. J.

*MARTIN, DE LOSS, U. S. Radio Inspector, Dept. of Commerce, 204 Federal Bldg., Seattle, Wash.

MASSEY, NORMAN EARL, Chief Electrician, Public Service Electric Co., 15th & Mickle Sts., Camden, N. J.

*MATSON, JOHN J., Consulting Engineering Dept., General Electric Co.; res., 1003 Nott St., Schenectady, N. Y.

MCFARLAND, JAMES CLARE, Construction Engineer, Turner Engineering Co.; res., 745 Central Ave., Detroit, Mich.

MCKAY, WILLIAM, Asst. Field Supt. (Electrical), Lewis Roth & Co., 1012 Liberty Bldg., Philadelphia, Pa.

MEAGHER, CHARLES F., Foreman, Transformer Shop, City Light Dept.; res., 6053 2nd Ave., N. W., Seattle, Wash.

MIETH, CHARLES AUGUST, Electrical Engineer, with Robert L. Hailey, New York; res., 1639 E. 13th St., Brooklyn, N. Y.

*MILLER, E. CLARENCE, Chief Testing Engineer, Kilbourne & Clark Mfg. Co.; res., 504 E. Republican St., Seattle, Wash.

MILLER, HAROLD REDMORE, Radio Electrician, U. S. Navy Yard; res., 136 10th St., Norfolk, Va.

MOTOKAWA, ICHIRO, Engineer, Transformer Engineering Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 333 Barnes St., Wilkinsburg, Pa.

MOWRY, HARRY WHEELOCK, Equipment Engineer, Hawthorne Station, Western Electric Co., Chicago; res., 3326 Home Ave., Berwyn, Ill.

NEWTON, JOHN MILTON, Engineer, The Roland T. Oakes Co., Holyoke; res., 53 Chase Ave., Springfield, Mass.

NICHOLS, EARLE GLENN, Elec. Inspector & Tester, Electrical Dept., Iowa Ry. & Lt. Co.; res., 1439 1st Ave., Cedar Rapids, Iowa.

O'DONNELL, ELMER C., Sub-Foreman, Installation & Inspection Dept., United Electric Light & Power Co.; res., 52 St. Nicholas Place, New York, N. Y.

OLANDER, FRANK BERNARD, Tester of Electric Apparatus, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

O'LEARY, JOHN WILLIAM, Secretary & Treasurer, Arthur J. O'Leary & Son, 5757 West 65th St., Chicago, Ill.

ORTH, SYLVESTER A., Foreman, Meter Testing Dept., The Detroit Edison Co.; res., 153 Linsdale Ave., Detroit, Mich.

OSBORNE, RALPH WILLOUGHBY, Telephone Inspector, Hydro-Elec. Pr. Comm. of Ontario; res., 15 Tome Ave., Hamilton, Ontario.

OSWALD, EARL PAUL E., Electrical Engineer, Ford Motor Co., Highland Park; res., 149 Hogarth Ave., Detroit, Mich.

OVERPECK, JAY HAROLD, General Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 407 Todd St., Wilkinsburg, Pa.

OYAMA, MASAYASU, Switchboard Engineer, Westinghouse Elec. & Mfg. Co.; res., 305 W. 150th St., New York, N. Y.

PARKS, HENRY FRANCIS, Maintenance & Construction, American Theatre, Room 9, Concord Block, Butte, Mont.

PAUL, SEYMOUR, Editor, *Panama Canal Record*, Balboa Heights; res., Ancon, C. Z.

PENN, JOSEPH EARL, Shop Supt., Elliott Electric Co.; res., 1441 Euclid Ave., Cleveland, Ohio.

PHILLIPPI, CLAUDE A. F., Chief Electrician, Penn Hardware Co.; res., 229 S. 4th St., Reading, Pa.

*PRITCHARD, J. F., Gen. Supt., Ice & Elec. Depts., Consumers Light & Power Co., Ardmore, Okla.

PROBST, R. OTTO, Electrical Engineer, Indiana & Michigan Electric Co.; res., 334 N. Hill St., South Bend, Ind.

RE QUA, FREDERICK LIVINGSTON, Asst. in Research Laboratory, Cutler-Hammer Mfg. Co.; res., Stratford Arms, Milwaukee, Wis.

RICKER, CLAIRE WILLIAM, Instructor in Electrical Engineering, Mass. Institute of Technology, Cambridge; res., 65 Newport St., Arlington, Mass.

ROESER, EDWARD ADAM, Industrial Engineer, Rochester Railway & Light Co., 34 N. Clinton Ave., Rochester, N. Y.

RORER, WILLIAM NYCE, Telephone Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

RUBEL, WALTER G., Asst. Constr. Engr.. Mountain States Tel. & Tel. Co.; res., 134 Pearl St., Denver, Colo.

SANBORN, CARL H., Electrical Engineer, Monks & Johnson, 78 Devonshire St., Boston; res., 99 Summer St., Somerville, Mass.

SANBORN, JOHN FREEMAN, Construction Foreman, General Electric Co., 120 Broadway, New York; res., 605 E. 7th St., Brooklyn, N. Y.

SCOTT, ROBERT CRAIG, Electrical Operator, Hydro-Electrical Power Comm.; res., Sydenham St., Dundas, Ont.

SHAY, JOHN, General Foreman, Installation & Inspection Depts., United Electric Light & Power Co.; res., 422 W. 20th St., New York, N. Y.

SIFTON, EDGAR IVON, Chief Engineer and General Manager, City of Hamilton, City Hall; res., 33 Markland St., Hamilton, Ont.

*SILVER, BENJAMIN LAMB, Electrical Engr., Transmission Laboratory, Western Electric Co., 463 West St., New York, N. Y.

*SMALL, WALTER GARFIELD, Supt. of Distribution, Edison Elec. Illuminating Co.; res., 12 Cottage St., Brockton, Mass.

SPANGLER, CHARLES H., Experimental Electrical & Mechanical Work, 12 S. 5th St.; res., 944 N. 11th St., Reading, Pa.

SPERRY, S. MERKEL, Testing of Main & Substation Equipment, Metropolitan Edison Co., 12 S. 5th St., Reading, Pa.

SQUIRES, HAROLD WORTH, Design & Test Engineer, Development Laboratory, Research Corporation, Brooklyn; res., Amityville, N. Y.

STARR, RONALD HEBER, Sales Engineer, Moloney Electric Co. of Canada Ltd., 1221 Traders Bank Bldg., Toronto, Ont.

ST. AUBIN, ADOLPHE A., Electrical Engineer, Gulf Pulp & Paper Co., Clarke City, P. Q., Canada.

STEPHENS, HOWARD ORR, Engineer, Transformer Dept., General Electric Co.; res., 95 Livingstone Ave., Pittsfield, Mass.

STEVENS, THOMAS W., Foreman of Domestic Power & Service Dept., City Light Dept.; res., 3828 Corliss Ave., Seattle, Wash.

*SUEN, SYLVANUS THOMAS, Chief Engineer, Amoy Electric Light & Power Co. Ltd., Amoy, China.

SWARTZ, BENJAMIN FRANKLIN, Engineer, Experimental Dept., Burke Electric Co.; res., 548 W. 9th St., Erie, Pa.

SYLVESTER, WILBER VINCENT, In charge of Tel. Systems & Underground records, City Light Dept.; res., 1122 33rd Ave. So., Seattle, Wash.

TERPSTRA, D., Pres., Old Dominion Pr. Co., & Gen. Mgr., Wise Coal & Coke Co.; res., Dorchester Va.

*TODD, WILLIAM BOOTH, Elec. Engineer, Engg. Dept., E. I. du Pont de Nemours Co., Wilmington, Del.; res., Chester, Pa.

URIBE, LUIS E., Asst. to Chief Engineer, "La Compania de Fuerza y Luz," Panama City, R. P.

URICH, PAUL RANDOLPH, Foreman of Electric Cranes & Elevators, General Electric Co.; res., 609 Ash St., Erie, Pa.

VAN DYKE, KARL S., Engineering Dept., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

VAN INWEGEN, JOHN WARNER, Substation Operator, The United Electric Light & Power Co., New York; res., 47 Remington Ave., Jamaica, N. Y.

VERNOR, WILLIAM MILLER, General Engineering Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1300 Wood St., Wilkinsburg, Pa.

WHEELER, JOHN J., Electrical Engineer, Western Electric Co., New York; res., 29 St. Johns Place, Brooklyn, N. Y.

WINTERROTH, WILLIAM CHARLES, Sales Engineer, Mechanical Appliance Co., 327 South La Salle St., Chicago, Ill.

WORDEN, RIEL JARVIS, Gen. Foreman Station Maintenance, Hydro-Electric Power Comm. of Ontario, Hamilton; res., Dundas, Ont.

WRIGHT, ERNE ALOYSIUS, Electrical Engineer in Charge, Eden Mining Co., Bluefields, Nicaragua, C. A.

WROATH, LEON HENRY, Electrical Engineer, Engineering Inspection Dept., Western Electric Co., 30 Irving Place, New York, N. Y.

*Former enrolled Student.

Total 126.

ASSOCIATES RE-ELECTED MAY 17, 1918

FREEMAN, WALTER C., Advertising Manager, Stromberg-Carlson Tel. Mfg. Co.; res., 121 Corwin Road, Rochester, N. Y.

KLENK, FERNAND FEIR, Test Foreman, Electrical Dept., B. & O. R. R.; res., 2217 Cecil Ave., Baltimore, Md.

QUINAN, GEORGE ELY, Engineer, Puget Sound Traction, Light & Power Co.; res., 203 W. Comstock St., Seattle, Wash.

WRIGHT, JOHN W., Asst. Engineer, Bell Tel. Co. of Pennsylvania; res., 5217 Pine St., W. Philadelphia, Pa.

MEMBER RE-ELECTED MAY 17, 1918

SWEETNAM, A. H., Electrical Engineer, Stone & Webster, Boston; res., 97 Winthrop Road, Brookline, Mass.

MEMBERS ELECTED MAY 17, 1917

BOLLING, BARTLETT, JR., Electrical & Mechanical Engineer, Wolverine Copper Mining Co., Mohawk Mining Co., Kearsarge, Mich.

CAPARÓ, JOSÉ ANGEL, Prof. of Elec. Engineering, Univ. of Notre Dame, Notre Dame, Ind.

CHANDLER, WILLIAM DRIVER, Electrical Expert Aide, U. S. Navy Yard, New York; res., 139 Shepherd Ave., Brooklyn, N. Y.

KNOLLMEYER, LOUIS FREDERICK, Chief Inspector, Pittsfield Works, General Electric Co.; res., 835 North St., Pittsfield, Mass.

MOXEY, LOUIS W., JR., Vice-Pres. & Engineer, Keller-Pike Co.; res., 7437 Sprague St., Philadelphia, Pa.

NICHOLS, GEORGE B., Chief Engineer, State Architect's Office, Albany, N. Y.

PIGG, HOWARD F., Electrical & Mechanical Engineer, Witherbee, Sherman & Co., Mineville, N. Y.

SHREVE, JOHN NELSON, President, Electric Cable Co., 10 East 43rd St., New York; res., Scarsdale, N. Y.

WATERBURY, GRENVILLE FURMAN, Vice-President, Electric Cable Co.; res., 255 W. 84th St., New York, N. Y.

WHEELER, RICHARD HOWES, Manager of Construction, Area "M," U. S. Government Explosives Plant "C," Nitro, W. Va.

FELLOW ELECTED MAY 17, 1918

ALDRIDGE, THOMAS HENRY UNITE, Engineer-in-Chief & Manager, Electricity Dept., Shanghai Municipal Council, Shanghai, China.

TRANSFERRED TO GRADE OF FELLOW, MAY 17, 1918

BURROWS, CHARLES W., Associate Physicist, Bureau of Standards, Washington, D. C.

HALL, DAVID, D. C. Section Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

RHODES, GEORGE I., Mechanical and Electrical Engineer, Ford, Bacon & Davis, New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER, MAY 17, 1918

EDWARDS, IRVING W., 1st Lieut. Ordnance R. C., United States Army, Birmingham, Ala.

HULL, ARTHUR H., Electrical Engineer, Station Design, Hydroelectric Power Commission of Ontario, Toronto, Ont.

RICHARDS, WILLIAM E., Superintendent, Electric Dept., Toledo Railways & Light Co., Toledo, O.

SCHERIL, HENRY, Designing Engineer, Crocker-Wheeler Co., Ampere, N. J.; Instructor in Electrical Engineering, Cooper Union, New York, N. Y.

WHITNEY, ROY F., General Manager and Treasurer, Peoples Gas & Electric Co., Oswego, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before June 30, 1918.

Argemi, C., Jr., Ciego de Avila, Cuba.
Argo, G. G., Toronto, Ont.
Arrowsmith, S. V. C., Erie, Pa.
Austin, W. M., (Member), Swissvale, Pa.
Ballou, H. P., Mulberry, Fla.

Barclay, S. F., Sheffield, Eng.
Barnard, T. H., Hamilton, Ont.
Barrows, H. T., Hartford, Conn.
Beck, E. F. W., Brooklyn, N. Y.
Bethenod, J., Paris, France
Boddie, C. A., E. Pittsburgh, Pa.
Bolze, R. A., E. Pittsburgh, Pa.
Boyce, R. A., Belvidere, Ill.
Brady, J. B., Erie, Pa.
Capps, G. H., Gerat Falls, Mont.
Cartmill, J. E., Kenova, W. Va.
Cary, E. S., Evansville, Wis.
Clark, D. B., Washington, D. C.
Clark, G. H., (Member), Washington, D. C.
Cole, F. H., Omaha, Neb.
Cornell, A. C., Denver, Colo.
Costello, J. J., Boston, Mass.
Crouse, J. A., New York, N. Y.
Daniel, W. R., New York, N. Y.
Dashley, L. H., Portland, Ore.
Davies, H. C., Toronto, Ont.
Drewry, G. F., Toronto, Ont.
Engelke, W. H., New York, N. Y.
Enos, H. A., Detroit, Mich.
Eunson, W. H., E. Pittsburgh, Pa.
Farley, W. R., E. Pittsburgh, Pa.
Gerrie, W. H., Toronto, Ont.
Gifford, W. M., Toronto. Ont.
Goetzmann, A. J., Milwaukee, Wis.
Goodwin, A. C., Port Credit, Ont.
Hadrys, F. V., Philadelphia, Pa.
Hamilton, R. H., (Member), Newport, R. I.
Hammann, A. M., Niagara Falls, N. Y.
Harrison, J., Nanaimo, B. C.
Hecksher, O., (Member), Panama, R.P.
Hester, E. A., E. Pittsburgh, Pa.
Hodson, R. E., Philadelphia, Pa.
Holy, G. H. F., E. Pittsburgh, Pa.
Hopkins, H. G., E. Pittsburgh, Pa.
Howland, L. S., Boston, Mass.
Hughes, J. L., Pittsfie d, Mass.
Jackson, W. B., Bridgeport, Conn.
James, T. C., Toronto, Ont.
Jensen, C. H., Castlecliff, N. Z.
Johnston, H. H., E. Pittsburgh, Pa.
Kitchen, J. B., Toronto, Ontario
Knoop, R. M., Gatun, C. Z.
Lansil, C. E., Cambridge, Mass.
Leuschen, P. A., Erie, Pa.
Lloyd, J. H., Panama, R. P.
Lyon, F. J., Waterbury, Conn.
Lyons, B. F., (Fellow), Beloit, Wis.
Mac Mahon, R. A., Paris, France
Mackey, E. H., Philadelphia, Pa.
MacNeill, J. B., E. Pittsburgh, Pa.
McCaffery, J. J., S. Bend, Ind.
Maeyer, C. F., Erie, Pa.
Maina, A., Washington, D. C.
Maxfield, M. J., Hammond, Cal.
McBride, A. H., Toronto, Ont.
McElroy, T. F., Trenton, N. J.,
Newill, E. B., E. Pittsburgh, Pa.
Parker, J. S., Toronto, Ont.
Paul, B., Glasgow, Scotland
Pickering, D. A., E. Pittsburgh, Pa.
Pugh, E., Lafayette, Ind.
Pulham, G. B., Vancouver, B. C.
Quinn, W. P., Gatun, C. Z.
Rifenburg, R. C., Cleveland, Ohio
Rines, D., E. Pittsburgh, Pa.
Ross, R. J., Philadelphia, Pa.
Rossi, R. T., Trenton, N. J.,
Schirmer, C. T., Roxbury, Mass.
Schoenburg, V. A., Chicago, Ill.
Seltzer, C. B., Baltimore, Md.
Shaw, D., (Member), New York, N. Y.
Shearer, C. W., E. Pittsburgh, Pa.
Shelton, H. E., Wilmington, Del.
Spagnola, S., Brooklyn, N. Y.
Stevens, A. C., Pittsfield, Mass.
Stuart, C. E., (Member), Washington, D. C.
Taylor, D. W., LaCrosse, Wis.
Tempest, M. L., Boston, Mass.
Walsh, H. W., New York, N. Y.
Welge, D., Mason, Nev.

Total 90

STUDENTS ENROLLED
MAY 17, 1918

9567 Crown, V.M., Armour Inst. of Tech.
9568 Vafier, H. C., N. Y. Electrical Sch.
9569 Mosher, W.B., Johns Hopkins Univ.
9570 Eubeler, F. L. X., N. Y. Electrical School
9571 Lyne, J. L., Univ. of Neb.
9572 Catts, E. P., Delaware Coll.
9573 Osterbrock, W. C., Univ. of Cinn.
9574 Hoey, W. B., Delaware Coll.
9575 Alexander, J. W., Delaware Coll.
9576 Cannon, W. D., Delaware Coll.
9577 Porter, J. W., Univ. of Oklahoma
9578 Turner, H.I., Worcester Poly. Inst.

9579 Eresian, E. H., Worcester Poly. Inst.
9580 Richardson, M. W., Worcester Poly. Inst.
9581 Knowlton,H.J.,Michigan Agr.Coll.
9582 Bock, A. P., Michigan Agr. Coll.
9583 Carrow, H.G., Michigan Agr. Coll.
9584 Dee, T. C., Michigan Agr. Coll.
9585 Golden, J. B., Mich'gan Agr. Coll.
9586 Karkan,E. L., Michigan Agr. Coll.
9587 Kling, R. B., Michigan Agr. Coll.
9588 Noddins,R.W.,Michigan Agr. Coll.
9589 Sayre, E. E., Michigan Agr. Coll.
9590 Shenefield,A.A.,MichiganAgr.Coll.
9591 Siefert, W.A., Michigan Agr. Coll.
9592 White, C. C., Michigan Agr. Coll.
9593 Quinlan, W. J., Columbia Univ.
9594 Preston, A. H. J., Union Coll.
9595 Wolferz, A. H., Cooper Union
9596 Bond, LeR. W., Worcester Poly. Inst.
9597 Brown, H. M., Wentworth Inst.
9598 Worthington, H. E., School of Engg. of Milwaukee.
9599 Bradford, L. L., Wentworth Inst.
9600 Blodgett, R. R., Iowa State Coll.
9601 Jennings, A. F., Iowa State Coll.
9602 Dolezal, R., Iowa State Coll.
9503 Hughes, W. E., Iowa State Coll.
9604 Gustafson, A. L., Iowa State Coll.
9605 Briley, R E., Iowa State Coll.
9606 Hein, V. L., Iowa State Coll.
9607 Bany, H., Iowa State Coll.
9608 Moore, W. S., Dealware Coll.
9609 Dickerson,F.A., Penna. State Coll.
9610 Walton, A. S., Delaware Coll.
9611 Critzas, D. J., Cooper Union.
9612 Graham, M. E., Univ. of Ill.
9613 Perry, D. B., Univ. of Maine
9614 Gansner, W. G., Univ. of So. Cal.
9615 Hunt, L. F., Univ. of So. Cal.
9616 Kopp, T. E., Univ. of So. Cal.
9617 Swanberg, E. DeF., Univ. of Ill.
9618 Rockwell, E. W., Univ. of So. Cal.
9619 Risser, W. S., Univ. of Ill.
9620 Bottimer, G. W., Univ.of Mich.
9621 Meehan, T. P., Tri-State College
9622 Johnson, W. W., Rensselaer Poly. Inst.
9623 Miller, A. R., Univ. of Ill.
9624 Jones, M. M., Univ. of 'll.
9625 Byberg, G., Engg. School of Milwaukee.
9626 Calhoun, E. N., Drexel Inst.
9627 Place, S. W., Drexel Inst.
9628 Hymes, H., Drexel Inst.
9629 Troth, R. H., Drexel Inst.
Total 63.

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 We t 39th Street.

Walter A. Fallon
(former address)
B. L. & R. Railway Co.,
Rochester, N. Y.

Carl L. Gerhardt
(former address)
Throop College of Tech.,
Pasadena, Cal.

Morris Sheffler
(former address)
202 Riverside Drive,
Apt. 3 center,
New York, N. Y.

Hamilton James
(former address)
Stuart James & Cooke,
Commonwealth Bldg.,
Pittsburgh, Pa.

Bertrand Smith
(former address)
Sunnyside Mining &
Milling Co.,
Eureka, Colo.

E. Lee Smith
(former address)
4417 Forest Ave.,
Kansas City, Mo.

PERSONAL

William Baum, who has been Dean of the School of Engineering of Milwaukee for the last two years has resigned his position to become research engineer for The Milwaukee Electric Railway & Light Co., which office has been newly created. This change is due to Professor Baum's desire to re-enter the industrial field.

JOHN D. BALL, Professor of Electrical Engineering at the School of Engineering of Milwaukee has been assigned to the Deanship left vacant by the resignation of Mr. William Baum.

CLARENCE SHELDEN, who suffered a stroke of paralysis in August, 1916, while acting as General Superintendent of the New York & Queens Electric Light & Power Co., has so far recovered as to be able to resume professional work with New York office of the General Electric Company.

D. C. and WM. B. JACKSON, Engineers, announce that on account of two members of the firm having gone into the National Service, and the third member expecting to do so as soon as practicable, they will close their offices and suspend business for the further duration of the war, as soon as the various pieces of work with which they are now occupied can be completed. They expect to resume business after the conclusion of the war.

OBITUARY

PROF. F. R. HUTTON, past-president of the American Society of Mechanical Engineers, died on May 14 at the age of sixty-five years. Professor Hutton was graduated from the School of Mines, Columbia University, 1876. He held various positions on the faculty of Columbia and in 1892 became head of the mechanical engineering department which he continued to direct until his resignation in 1907 at which time he was elected Professor Emeritus. Professor Hutton became secretary of the A.S.M.E. in 1883. He declined reelection in January 1906 and in the following December was elected president. He was a member of the conference and building committee of the United Engineering Society, which committee was organized to plan the Engineering Society's Building at 29 West 39th Street, New York. In addition to numerous other activities Professor Hutton was an author, lecturer and extensive contributor to the technical press.

E. E. CARLSON, of Hobart, Indiana, an Associate in the A.I.E.E. died on May 8, 1918 after an illness of over a year. Mr. Carlson has been connected with the Illionois Steel Co., Gary Works since 1908.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

OPPORTUNITIES FOR SERVICE

V-363. Wanted: Experienced electrical and mechanical draftsmen. Salaries $150 to $175 per month.

V-364. Young engineer over draft age, single, to go to head office in Chile S. A., of company operating several plants in nitrate district. Should have some experience in industrial cost analysis and efficiency work, in addition to general engineering experience. Salary $3,000 year at commencement.

V-365. Young man without any experience for meter department and young man with potentiometer experience for standardizing portable instruments.

V-366. Wanted: Instructor in electrical engineering in middle west state institution. $1,200 for nine or ten months. Research work will be encouraged and opportunity for teaching experience will be given in both laboratory and classroom courses. Graduation from good technical institution required. Practical experience desirable but not indispensable.

V-367. Wanted: An assistant professor of electrical engineering in southwestern university. Salary first year $1,700, second year $1,900. Applicant expected to teach senior and junior subjects. Two or three years teaching experience a prerequisite. Work starts September, 1918.

V-368. Wanted: Recent technical graduates, male or female, for general electrical engineering work with large central station company in Greater New York.

V-369. The engineering and drafting department of a large electrical construction firm has a vacancy for a young engineer with some experience in design and installations of electrical distributing systems, switchboards, etc., in commercial and industrial buildings. Technical education preferred. Also for an engineer with experience in electrical and mechanical design and construction of power plants and substations. Apply by letter only, giving age, education, experience and salary: L. K. Comstock & Company, 21 East 40th Street, New York City.

V-370. Instructor wanted. It is expected that there will be an instructorship in electrical engineering at Leland Stanford Jr. University to be filled for at least two years beginning October 1, 1918. Applicants are requested to send full information concerning their qualifications in first letter; also to have sent direct to the undersigned two or more letters from persons in the engineering or educational field who are well qualified to judge of the merits of the applicant as a teaching engineer. Name salary expected and state exact status with respect to draft. Address: J. C. Clark, 151 Embarcadero Road, Palo Alto, California.

V-371. Wanted: Young men for sales engineering, productive engineering, and experimental engineering work in large electrical manufacturing firm in Middle West. Applicants must have complete high school training and the equivalent of at least two years technical training, and preferably be technical graduates from university of good standing. In reply state training and experience in detail, salary desired, draft classification and references.

V-372. Electrical draftsman experienced in power-house design. State age, experience and salary.

SERVICES AVAILABLE

972. Electrical engineer, technical, nine years' experience in specification writing, designing, and supervising installation of electrical and mechanical equipment for buildings and isolated power plants; one year's experience in valuation engineering; will be available about May 15. Salary $2,500 per annum.

973. Graduate mechanical and electrical engineer with eighteen years' broad business and technical training, (three years in Russia), desires responsible position with contracting or or exporting concern of strong financial standing that is prepared for large business in Russia. Familiar with export organization; also construction and operation of all kinds of power plants. Now located in Sweden.

974. Electrical distribution engineer, chief for small power company or assistant for large company in southwest. Technical graduate with three years' experience in design and layout of new and revamping of old overhead and underground distribution systems and extentions. Age 26, draft exempt. Correspondence invited and references furnished.

975. Technical graduate in electrical engineering with broad experience desires position with railway, light or manufacturing company offering a good opportunity of developing into an executive position.

976. Electrical engineer, university graduate, Associate A.I.E.E., desires position in experimental and development laboratory, preferably with manufacturer in middle west. Unmarried. Age 24. General Electric experimental experience on small motors, also one year with distribution department large central station. At present employed, but can change on ten days' notice. Salary $1,800.

977. Electrical and mechanical engineer, married, nine years' experience on power station operation and construction work. Has been in charge of large hydroelectric stations, high voltage transmission system and substations. Desires executive position with large power or holding company.

978. Chief electrical engineer. At present with a concern whose work the

war has diverted from their electrical line. Married. Draft class IV. Experience covers the designing and developing of high tension transforming and rectifying devices. Application of modern production methods. Operation of sales service plans. Available at reasonable notice. Salary $2,400.

979. Electrical engineer, superintendent or consulting engineer, university graduate (E.E. two degrees). Five years with consulting engineering firm, four years general manager of electric and waterworks ulilities. Can take charge of power plant design and construction or plant efficiency work, testing, etc. Start at $2,400 with advancement prospects.

980. Man having held positions of master mechanic, office engineer, chief electrician, foreman, etc., in connection with mechanical and electrical equipment on layout, erection, operation and maintenance as used about steam, and hydroelectric plants, mines, mills and smelters with some electric railway experience covering some twenty years. Healthful local or foreign location desired.

981. Civil and electrical engineer, fourteen years broad experience in design, construction and operations of steam, hydraulic and electrical machinery and apparatus of all kinds, transmission lines, hydroelectric developments, etc. Six years in charge of some of the largest power systems in this country. Open for engagement. Interview requested.

982. Electrical engineer, draft exempt, married. Experienced designer and draftsman on power stations, transmission lines and switchboards. Wants position as assistant engineer with hydroelectric power company or consulting engineer who can offer future opportunities to right man. Salary about $175 monthly.

983. Electrical engineer, 31, married, Class 4-A; seven years' experience large western power and electric railway companies; design, construction and valuation; especially qualified to undertake complete inspections for valuation of power or electric railway properties. Familiar with cooperation auditing methods. Available in one month. Minimum salary $2,100.

984. Assistant professor of electrical engineering in large middle western university, 36 years of age, desires position as head professor, while at the age at which he can do his best work. Author well-known textbook; member A.I.E.E., N.E.L.A. Ten years teaching. Five years commercial experience Some consulting and testing experience.

985. Electrical engineer, extensive teaching experience in electrical subjects. Seven years design and operation of power plants, electrical lay-out work, etc. Good executive ability. Desires position as Manager of power plant in field where development is desired, or head of electrical department in technical school. Salary $2,500.

986. Technical graduate 1915, with three years electrical engineering laboratory and teaching experience, desires work of experimental nature in electrical or mechanical engineering. Location east. Class IV of draft. Married, age 26. Salary $150 per month. Will consider any kind of work where my experience will be of value.

987. Teacher in electrical engineering, age 34, degrees B.A. and E.E., ten years' teaching experience, married, desires better and more responsible position. At present in charge of electrical engineering department of small western engineering college. Prefer teaching laboratory, elementary theory or applied courses. Least salary $2,500.

988. Executive and engineer, with six years electrical and mechanical experience in the design, operation and maintenance of various electrical apparatus, including railway and shop practise and also some sales work, is open for engagement; available on a month's notice, would prefer to locate in the East.

989. Electrical engineer, technical graduate, with experience in the manufacture of electrical machinery and the construction and operation of steam and hydroelectric power plants, available on short notice.

990. Electrical engineer, 30 years of age, single, with technical and scientific training in telephone, high frequency and electrochemical work, as well as in general electrical engineering. Six years' experience in development, design and research work with leading electrical companies of the world. Exempt from draft. Best references available.

991. Self-reliant, competent, electrical engineer. Varied office and responsible field experience. Demonstrated ability to produce results. Tested executive and organizer. Tactful. Pleasing personality. Four year electrical course. Premier polytech-

nic; graduate chemist. Travelled. Linguist. Now connected with war industry. Desire change to find wider scope and improve position. War activity essential.

992. Electrical engineer, with two years' experience in operating, six years' experience as engineer and designer of large substation and generating stations. Now completing the layout of electrical equipment of large steel rolling mill. Capable and accustomed to handling engineering problems. Desires responsible position with progressive company in Chicago or South.

993. Electrical engineer with twelve years practical experience in power installation, interior wiring and estimating, wishes position. Can handle men. Age 26, Class IV in draft. Married Minimum salary $1,800. Available immediately.

994. Young electrical graduate desires position with electric railway or power company. Familiar with central station and electric railway apparatus. Plenty of originality and ingenuity. Best of references. Middle West preferred. Draft class III, a, b, and k. In testing department of large manufacturer at present.

ACCESSIONS TO THE UNITED ENGINEERING SOCIETY LIBRARY

(From April 1, 1918, to May 1, 1918.)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made. These are taken either from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

AGRICULTURAL BACTERIOLOGY:

A Study of the Relation of Germ Life to the Farm with Laboratory Experiments for Students. Micro-organisms of Soil, Fertilizers, Sewage, Water, Dairy Products, Miscellaneous Farm Products and of Diseases of Animals and Plants. By H. W. Conn. 3rd edition, revised by Harold Joel Conn. Phila., P. Blakiston's Son & Co., (copyright 1918) 10+357 pp., 63 illus., 8 x 6 in., cloth, $2.

The third edition has been brought up to date by the inclusion of the advances in bacteriological knowledge since the previous edition.

AIRCRAFT MECHANICS HANDBOOK:

A Collection of Facts and Suggestions from Factory and Flying Field to Assist in Caring for Modern Aircraft. By Fred H. Colvin. 1st edition. N. Y. McGraw-Hill Book Company, Inc.. Lond., Hill Publishing Company, Ltd., 1918. 402 pp., 193 illus., 28 tab., 7 x 5 in., flexible cloth, $3.

A manual of the best practise in inspecting, adjusting and repairing airplanes, prepared for use by the machinists and riggers who are now being trained. Describes the construction, erection and testing of the planes, the various engines in use and the methods of caring for them. An account of the Canadian Training Camp at Borden is also given. Useful tables and a glossary are included.

ARTIFICIAL DYE-STUFFS:

Their Nature, Manufacture, and Uses. By Albert R. J. Ramsey and H. Claude Weston. Lond., George Routledge & Sons, Ltd.; N. Y., E. P. Dutton & Co., 1917. 212 pp., 24 illus., 9 x 6 in., cloth, $1.60. (Gift of E. P. Dutton & Co.)

A brief introductory work on the artificial dyestuff industry, written for students and business men with little knowledge of organic chemistry, in which the industrial processes of the manufacture of dye-stuffs, and the nature of the substances used, are explained at some length.

AVIATION CHART:

Location of Airplane Power Plant Troubles Made Easy. By Victor W. Page. N. Y., The Norman W. Henley Publishing Co., 1918. 46 x 32 in., paper, 50 cts.

A large chart outlining all parts of a typical airplane power plant, showing the points where trouble is apt to occur and suggesting remedies for the common defects. Intended especially for aviators and aviation mechanics on school and field duty.

COAL GAS RESIDUALS.

By Frederick H. Wagner. 2nd edition, revised and enlarged. N. Y.

McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Company, Ltd., (10 folded) 7 diagrams, 32 tab., 9 x 6 in., cloth, $2.50.

The chief additions to this edition discuss the process of the distillation and tar products, and give further information on the product derived from spent oxide, the production of nitric acid, naphthalene, benzol and toluol. A chapter on the manufacture of sulfuric acid from spent oxide has also been added, and the typographical errors in the first edition have been corrected.

COLD DRAWN STEEL:

Bar Weights of Rounds, Flats, Hexagons and Squares; Weight Tables for Plates; Metric Conversion Tables; Cold Drawn and Hot Rolled Extras, and other Miscellaneous Tables (Cover title: Book of Weights). Issued by the Peerless Drawn Steel Co., Massillon, O., The Peerless Diawn Steel Co., 1918. 165 pp., 52 tab., 8 x 5 in., flexible leather, $3.

Instead of giving only the weight per foot of steel bars of various sizes, this book gives the totals for bars of all the usual lengths in feet. A number of other useful tables are added.

COMPLETE LIST OF BASE PRICES, DIFFERENTIALS AND EXTRAS ON IRON STEEL AND NONFERROUS PRODUCTS:

Fixed under Government Supervision. Cleveland, Penton Publishing Co., (copyright 1918) 42 pp., 8 x 6 in. paper, $2.

A convenient summary of the Government prices. Prepared by the Iron Trade Review and presented to subscribers to that journal.

CREATING CAPITAL:

Money-making as an aim in Business. By Frederick L. Lipman. Bost. and N. Y., Houghton Mifflin Co., 1918. 71 pp., 7 x 5 in., cloth, 75 cents.

HIGHER EDUCATION AND BUSINESS STANDARDS.

By Willard Eugene Hotchkiss. Bost. and N. Y., Houghton Mifflin Co., 1918. 109 pp., 7x 5 in., cloth $1. (Gift of the University of California Press).

Two essays delivered at the University of California on the Weinstock Foundation, established for the discussion of various phases of the moral law in its bearing on business life under the new economic order.

ELECTRICAL MEASUREMENTS:

A Practical Handbook Covering the Design and Construction of Measuring Instruments and their uses in Measument of Current, Resistance, and Commercial Power. with Special Reference to Watt-hour and Maximum Demand Meters. By O. J. Bushnell and A. G. Turnbull. Chic., American Technical Society, 1914. 171 pp., 139 illus., 2 pl., 8 x 6 in., cloth, $1.

The author's aim has been to supply an adequate description of the instruments and methods used for the measurement of electrical energy, and to show by diagrams exactly how meters should be connected under all conditions.

ELECTRODYNAMIC WAVE THEORY OF PHYSICAL FORCES:

Announcing the Discovery of the Physical Cause of Magnetism, of Electrodynamic Action, and of Universal Gravitation. Vol 1., Bulletins 1 to 6 inclusive. By T. J. J. See. Lynn, Mass., Thomas & P. Nichols & Son Co.; Lond., William Wesley & Son; Paris, A. Hermann et Fils, 1917. 14+158 pp., 21 diagrams, 4 pl., 1 chart, 6 tab. (1 folded) 12 x 10 in., paper, $5.

In these bulletins Dr. See presents his hypothesis that magnetism, electrodynamic action and universal gravitation are due to waves propagated with the velocity of light through the free ether and at slower rates through solid masses. The author believes that his investigations have finally solved the problem of the nature and mode of propagation of physical forces.

FIELD ARTILLERYMANS' GUIDE:

3-Inch Gun, 4.7- and 6-Inch Howitzer. Prepared by the officers of the 108th (2d Pa.) Field Artillery. 2nd revised edition. Phil., P Blakiston's Son & Co., (copyright 1918) 381 pp., 102 illus., 3 pl., 31 tab., 7 x 4 in., cloth, $1.75.

A pocket guide intended to serve the immediate needs of field artillerymen in the United States Army, by presenting the fundamentals of their duties.

FORGING:

Manual of Practical Instruction in Hand Forging of Wrought Iron, Machine Steel, and Tool Steel; Drop Forging; and Heat Treatment of Steel, Including Annealing, Hardening, and Tempering.

By John Jernberg. Chic., American Technical Society, 1917. 131pp., 206 illus., 2 pl., 3 tab., 8 x 6 in., cloth, $1.

A concise account, intended primarily for students. Describes the methods and tools used in hand forging, as well as the usual shop practise in hardening, annealing and tempering steel.

GALVANIZING AND TINNING:

A Practical Treatise on the Coating of Metal with Zinc and Tin by the Hot Dipping, Electro Galvanizing, Sherardizing and Metal Spraying Processes with Information on Design, Installation and Equipment of Plants. By W. T. Flanders. N. Y., David Williams Co., 1916. 350 pp., 142 illus., 3 charts, 5 tab., 9 x 6 in., cloth, $4. (Gift from the U.P. C. Book Co.)

Discusses the various processes in a practical way, describing the machinery, materials and operations in detail. Intended as a guide in the installation and operation of galvanizing and tinning plants.

HANDBOOK OF HYDRAULICS:

For the solution of Hydraulic Problems. By Horace Williams King. 1st edition. N. Y., McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Company, Ltd., 1918. 16+424 pp., 91 illus., 112 tab., 2 diagrams, 7 x 4 in., flexible cloth, $3.

The author has attempted to simplify the work of the hydraulic engineer by studying critically the empirical formulas which have been devised and selecting those which are of value. These are presented with a description of their limitations and are accompanied by the necessary tables of coefficients. The twofold purpose of securing an accuracy consistent with the best experiments and of simplifying calculations has been kept in mind throughout the book.

INTERNAL COMBUSTION ENGINE MANUAL.

By F. W. Sterling. 4th edition. Wash., R. Berresford, 1917. 168 pp., 10 x 6 in., cloth, $2.

The manual, representing the course on internal combustion engines given at the U. S. Naval Academy, has been rewritten, enlarged and brought up to date. It now covers the theory and practise of these engines without including mathematical demonstrations and formulas. Particular attention is given to the engines used by the Navy and to aviation engines.

MANUAL OF MILITARY AVIATION:

Prepared for the use of Personnel of Aircraft Troops of the Army. National Guard and Reserve Corps; Officers of the Army, National Guard and Reserve Corps; Members of Military Training Camps; and Airmen in General. By Hollis Leroy Muller. Menasha, Wis., George Banta Publishing Co., (copyright 1917) 308 pp., 38 illus., 8 x 5 in., cloth, $2.50.

Contains the theoretical information necessary for efficient military aviation service. Intended for use as a text-book and as a reference work.

MACHINE SHOP PRACTICE.

By William B. Hartmann. N. Y. and Lond., D. Appleton & Co., 1917. 247 pp., 141 illus., 4 pl., 10 tab., 7 x 5 in., cloth, $1.10.

A presentation of the elementary principles of machine shop practice, intended for the instruction of beginners. Mathematical calculations are confined to the use of simple arithmetic.

MECHANICS OF THE HOUSEHOLD:

A Course of Study Devoted to Domestic Machinery and Household Mechanical Appliances. By E. S. Keene. N. Y., McGraw-Hill Book Company, Inc., Lond., Hill Publishing Company, Ltd., 1918. 10+391 pp., 273 illus., 11 tab., 8 x 6 in., cloth, $2.50.

This book is intended to be a presentation of the physical principles and mechanism employed in the equipment that has been developed for domestic convenience. Equipment for heating, ventilating, water supply, sewage disposal, lighting, etc., is described.

METALLURGICAL CALCULATIONS.

By Joseph W. Richards. N. Y., McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Company, Ltd., 1918. 23+675 pp., tab., 10 x 7 in., cloth, $5.

A convenient one-volume edition of the work, in which errors occurring in earlier ones have been corrected and new physical and chemical data have been added.

THE MODERN MILK PROBLEM:

In Sanitation, Economics, and Agriculture. By J. Scott MacNutt. N.Y., The Macmillan Company, 1917. 11+258 pp., 22 illus., 16 pl., 9 x 6 in., cloth, $1.

Written to supply a convenient survey of the main aspects of the milk problem, which will emphasize the practical and economic as well as the sanitary factors involved. Intended for health officials, dairymen, legislators and others interested in better milk supplies.

POWER STATIONS AND TRANSMISSION:

A Comprehensive Treatise on Electric Power Station Equipment, Design, and Management, and the Erection and Maintenance of Proper Transmission Lines. By George C. Shaad. Chic., American Technical Society, 1917. 180 pp., 50 illus., 3 pl. 10 tab., 8 x 6 in., cloth, $1.

Presents concisely the important features of the topic. The treatment is largely descriptive and non-mathematical.

THE PRINCIPLES, OPERATION AND PRODUCTS OF THE BLAST FURNACE.

By J. E. Johnson, Jr., 1st edition. N. Y., McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Company, Ltd., 1918. 15+551 pp., 173 illus., 23 tab., 9 x 6 in., cloth, $5.

A thorough, detailed discussion of the operation of the blast furnace, including both the theoretical principles and the practise of the present day. Completes the author's treatise on the manufacture of pig-iron, begun in his work entitled "Blast Furnace Construction."

THE PRINCIPLES OF SANITARY TACTICS:

A Handbook on the Use of Medical Department Detachments and Organizations in Campaign. By Edward Lyman Munson. Menasha, Wis., George Banta Publishing Co., (copyright 1917) 305 pp., 13 maps, including 2 folded maps in covers, 8 x 5 in., cloth $2.15.

The author's desire has been to provide a text-book which will standardize the methods of instructing line and medical officers in the tactical use of the sanitary service with troops in campaign and will also give a thorough grounding in the fundamentals of sanitary tactics as a whole.

RADIO TELEPHONY.

By Alfred N. Goldsmith. N. Y., The Wireless Press, Inc., (copyright 1918) 247 pp., 226 illus., 9 x 6 in., cloth, $1.25.

The author has attempted in this work to give a full description of present methods of radiotelephony and of the various types of apparatus employed. The first systematic exposition of the subject to appear since 1907.

THE SCIENCE OF MANAGEMENT.

By Frederick A. Parkhurst. Cleveland, the author (copyright 1918) 203 pp., 7 tab., 9 x 6 in., cloth, $3.

A text-book prepared to accompany the author's course of thirty lectures, delivered during 1917-18 at the Case School of Applied Science.

SCIENTIFIC INDUSTRIAL EFFICIENCY.

By Dwight T. Farnham. Chic., Brick and Clay Record, 1917. 101pp., 34 illus., 10 x 6 in., cloth, $2.

In this book the author has endeavored to describe some applications of scientific management which have come under his observation during his experience as an engineer and executive. The examples given are chiefly taken from the clay products industry.

STATE SANITATION:

A Review of the Work of the Massachusetts State Board of Health. By George Chandler Whipple. Vol. 2. Cambridge, Harvard University Press, Lond., Humphrey Milford, 1918. 452pp., 17 illus., 3 pl., 1 por., 60 tab., 10x7 in., cloth, $2.50.

This volume contains abstracts of the leading articles on subjects relating to preventive medicine, hygiene and sanitation which are scattered through the annual and special reports of the Massachusetts State Board of Health published between 1869 and 1914. In addition, thirty-four of the most important contributions to sanitation are reprinted, with some abridgement.

TEXT-BOOK OF ADVANCED MACHINE WORK:

Prepared for Students in Technical, Manual Training, and Trade Schools, and for the Apprentice and the Machinist in the shop. By Robert H. Smith. 4th edition, revised and enlarged. Bost., Industrial Education Book Co., (copyright 1916) 648 pp., 680 illus., 44 tab., 8x5 in., cloth, $3.

A continuation of the author's "Principles of Machine Work." This volume treats of engine lathe work, drilling and boring machines, grinding, planing, milling, gear cutting and tool making. Careful explanations are given for each variety of work.

WAR ADMINISTRATION OF THE RAILWAYS IN THE UNITED STATES AND GREAT BRITAIN.

By Frank Haigh Dixon and Julius H. Parmelee. (Carnegie Endowment for International Peace, Division of Economics and History. Preliminary Econo-

mic Studies of the War) N. Y., Oxford University Press, 1918. 13+155 pp., 10x7 in., paper, $1. (Gift of the Carnegie Endowment for International Peace.)

An account of the methods used in the two countries and of the results achieved prior to December, 1917, during the period when the American railways were voluntarily cooperating with each other. The authors present a simple narrative, without attempting to draw conclusions.

WAR TIME CONTROL OF INDUSTRY: The experience of England. By Howard L. Gray, N. Y., The Macmillan Company, 1918. 15+307 pp., 8x5 in., cloth, $1.75.

A summary of the development and status of governmental control of industry in Great Britain, arranged to show its successive stages. Part of the information was collected for the Commercial Economy Division of the Council of National Defense. The book concludes with a comparison of English and American experience.

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Pittsfield	Mar. 25, '04	F. F. Brand	Neil Currie, Jr., General Electric Company, Pittsfield, Mass.
Portland, Ore.	May 18, '09	E. D. Searing	R. M. Boykin, North Coast Power Co., Portland, Oregon.
Rochester	Oct. 9, '14	Frank C. Taylor	C. T. Wallis, 138 Fairview Avenue, Rochester, N. Y.
St. Louis	Jan. 14, '03	H. W. Eales	Benjamin F. Thomas, Jr., 3869 Park Ave., St. Louis, Mo.
San Francisco	Dec. 23, '04	L. R. Jorgensen	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady	Jan. 26, '03	W. L. Upson	L. F. Millham, General Electric Company, Schenectady, N. Y.
Seattle	Jan. 19, '04	J. Harisberger	G. Dunbar, Seattle Light and Power System, Seattle, Wash.
Spokane	Feb. 14, '13	Charles A. Lund	J. E. E. Royer, Washington Water Power Company, Spokane, Wash.
Toledo	June 3, '07	W. A. Hill	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio.
Toronto	Sept. 30, '03	William G.Gordon	Ernest V. Pannell, 60 Front Street, West. Toronto, Ont.
Utah	Mar. 9, '17	A. S. Peters	H. T. Plumb, Newhouse Bldg., Salt Lake City, Utah.
Urbana	Nov. 25, '02	L. V. James	A. R. Knight, Univ of Illinois, Urbana,Ill.
Vancouver	Aug. 22, '11	R. F. Hayward	T. H. Crosby, Canadian Westinghouse Co. Vancouver, B. C
Washington, D. C.	Apr. 9, '03	Paul G. Agnew	J. Ernest Smith, McKinley Manual Training School, Washington, D. C.

Total 34

LIST OF BRANCHES

Name and when Organized		Chairman	Secretary
Agricultural and Mech. College of Texas	Nov. 12, '09	L. E. Tighe	F. V. Murrah, College Station, Tex.
Alabama Poly. Inst.	Nov. 10, '16	W. W. Hill	J. A. Douglas, P.O. Box 190, Auburn, Ala.
Alabama, Univ. of	Dec. 11, '14		
Arkansas, Univ. of	Mar. 25, '04	E. P. O'Neal	J. C. Douthit, University of Arkansas, Fayetteville, Ark.
Armour Institute	Feb. 26, '04	R. A. Newlander	Robert H.Rensch, The Armour Engineer, 33rd and Federal Streets, Chicago, Ill
Brooklyn Poly. Inst.	Jan. 14, '16	G. Hotchkiss	E. A. Demonet, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University	May 17, '10	C. W. Mason	Leon H. Noll, Bucknell University, Lewisburg, Pa.
California, Univ. of	Feb. 9, '12	A. J. Swank	G. F. Teale, University of California, Berkeley, Cal.
Carnegie Inst. of Tech.	May 18, '15	W. F. Eames	B. C. Dennison, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of	Apr. 10, '08		C. B. Hoffman, University of Cincinnati, Cincinnati, Ohio
Clarkson Col. of Tech.	Dec. 10, '15	R. H. Hoyt	E. S. Parks, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col.	Nov. 8, '12		
Colorado State Agricultural College	Feb. 11, '10	R. C. Richards	W. A. Stallings, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized		Chairman	Secretary
Colorado, Univ. of	Dec. 16, '04	Robert Newman	William N. Gittings, University of Colorado, Boulder, Colo.
Georgia School of Technology	June 25, '14	Reese Mills	Graham Granger, Georgia School of Technology, Atlanta, Ga.
Highland Park College	Oct. 11, '12		
Idaho, Univ of	June 25, '14	V. E. Pearson	L.J.Corbett,Univ.of Idaho,Moscow,Idaho.
Iowa, Univ. of	May 18, '09	P. S. McCann	A. H. Ford, State University of Iowa, Iowa City, Ia.
Kansas State Agr. Col.	Jan. 10, '08	L. N. Miller	M. H. Russell, Kansas State Agri. Col., Manhattan, Kansas.
Kansas Univ. of	Mar. 18, '08	Clarence Lynn	Robert W. Warner, 1428 Tennessee Street, Lawrence, Mass.
Kentucky, State Univ. of	Oct. 14, '10	J. M. Hedges, Jr.	Robert M. Davis, State University of Kentucky, Lexington, Ky.
Lafayette College	Apr. 5, '12	Harry C. Hartung	William Lash Lipps, 633 Parsons, Easton, Pa.
Lehigh University	Oct. 15, '02	R. H. Lindsay	R. D. Bean, 40 N. 7th Ave., Bethlehem, Pa.
Lewis Institute	Nov. 8, '07	Bernard Slater	Edwin, Verrall, Lewis Institute, Chicago.
Maine Univ. of	Dec. 26, '06	C. L. Springer	Donald B. Perry, University of Maine, Orono, Me.
Massachusetts Inst. of Tech.	Apr. 13, '17	Wm. H. Costello	George A. Elz, Massachusetts Institute of Tech., Cambridge, Mass.
Michigan Agric. College	Mar. 15, '18	R. A. Schenefield	W. A. Siefert, Mich. Agric. College, East Lansing, Mich.
Michigan, Univ. of	Mar. 25, '04	W. R. Harvey	T. W. Conant, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of	May 16, '16	Russell Ross	Ray McKibben, University of Minnesota, Minneapolis, Minn.
Missouri Univ. of	Jan. 10, '03	A. C. Lanier	D. P. Savant, University of Missouri, Columbia, Mo.
Montana State Col.	May 21, '07	Roy C. Hagen	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Olin J. Ferguson	Oskar E. Edison, University of Nebraska, Lincoln, Nebraska...
North Carolina Col. of Agr. and Mech. Arts	Feb. 11, '10	F. N. Bell	Landon C. Flournoy, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
North Carolina, Univ. of	Oct. 9, '14	P. H. Daggett	R. D. Ballew, University of North Carolina, Chapel Hill, N. C.
North Dakota, Univ. of	Feb. 15, '17	D. F. McConnell	Roy A. Wehe, University ,N. D.
Norwich University	June 28, '16		
Ohio Northern Univ	Feb. 9, '12	W. F. Parsons	A. J. Ferlic, 718 N. Main Street Ada, Ohio.
Ohio State University	Dec. 20, '02	E. S. Gunn	T. D. Robb, 124 West 10th Ave., Columbus, Ohio.
Oklahoma Agricultural and Mech. Col.	Oct. 13, '11		
Oklahoma, Univ. of	Oct. 11, '12	C. T. Hughes	C. H. Whitwell, University of Oklahoma, Norman, Okla.
Oregon Agr. Col.	Mar. 24, '08	L. Happold	Lawrence Fudge, Oregon Agri. College, Corvallis, Ore.
Penn. State College	Dec. 20, '02	H. A. Billig	P. J. F. Derr, State College, Pa.
Pittsburgh, Univ. of	Feb. 26, '14		
Purdue University	Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Queen's University(Ont.)	Jan. 11, '18	F. Kinnard	T. A. Sims, Queen's University, Kingston, Ont.
Rensselaer Poly. Inst.	Nov. 12, '09	W. J. Williams	Leroy C. Witt, Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst.	Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terra Haute, Ind.
Stanford Univ.	Dec. 13, '07	C. H. Suydam	Frank Miller, Stanford University, Cal.
Syracuse Univ.	Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of	Feb. 14, '08	J. A. Correll	W. J. Miller, University of Texas, Austin, Tex.
Throop College of Technology	Oct. 14, '10		
Virginia Polytechnic Institute	Jan. 8, '15	Baxter McIntosh	J. A. Carr, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of	Feb. 9, '12	Charles Henderson	J.Arthur Evans, University, Va.
Wash., State Col. of	Dec. 13, '07	B. Benz	Clarence E. Guse, 393 College Sta., Pullman, Wash.
Washington Univ.	Feb. 5, '04	R.W. MacDonald	Walter J. Skrainska, Washington University, St. Louis, Mo.
Washington, Univ. of	Dec. 13, '12	Chas. M. Lubcke	M. A. Whitman, University of Washington, Seattle, Wash.
West Virginia Univ.	Nov. 13, '14	H. B. Duling	F. L. Davis, West Virginia University, Morgantown, W. Va.
Worcester Poly. Inst.	Mar. 25, '04	B. Luther	N. L. Towle, Worcester Polytechnic Institute, Worcester, Mass.
Yale University	Oct. 13, '11	Brian O'Brien	G. P. Nevitt, 249 Park Street, New Haven, Conn.

Total 58

To be presented at the 34th Annual Convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 27, 1918.

THE OXIDE FILM LIGHTNING ARRESTER

BY CROSBY FIELD

ABSTRACT OF PAPER

The oxide film arrester is a new type of lightning arrester made up of a film of insulation in contact with a conducting powder. Upon the application of over-voltage, the insulation will be pierced, but the powder will very rapidly turn into insulation and plug any holes punctured in the original insulation by the over-voltage, thus forming in substance a resealing insulation. A brief description of this arrester is given together with the principles underlying its action and a comparison with other types of lightning arresters. Mention is also made of other characteristics of this combination which are not used in the present arrester, but which are being applied in other developments. A few notes of tests on the commercial arrester complete this paper. With the exception of the basic patents issued to the author this is the first time any disclosure has been made of this arrester.

THIS paper will be confined to a brief statement of the scientific principles underlying a new type of lightning arrester called the "oxide film arrester."* The functioning of this arrester depends upon the fact that certain dry chemical compounds can be changed with extreme rapidity from very good conductors of electricity to almost perfect non-conductors by the application of a slight degree of heat. Lead peroxide is a good example of such a substance. It has a specific resistance of the order of one ohm per inch cube. The resistance varies with the pressure to which it has been compressed. At a temperature of about 150 deg. cent. the lead peroxide (PbO_2) will be reduced to red lead, commercially known as minimum (Pb_3O_4). This has a specific resistance of about 24 million ohms per inch cube, At slightly higher temperatures this minimum will be reduced through the sesquioxide (Pb_2O_3) to litharge (PbO), which last named is practically an insulator. [A megger reading of infinity is obtained on a column 3 millimeters long (0.11 in.) and 5 square millimeters area (0.2 sq. in.)].

Again the oxides of bismuth give similar characteristics. There

*U. S. Patent No. 1,238,660—Crosby Field.

Manuscript of this paper was received April 24, 1918.

are, furthermore, several other compounds and mixtures of compounds that will give these same results.

Lead peroxide is normally in the physical state of a powder If this powder be placed between two electrodes and a current passed, the temperature due to the resistance at the contact of the peroxide and the metal will cause heat to be generated locally at the surface. When this heat is sufficient to create a temperature of about 150 deg. cent. a film of the lower oxides of lead

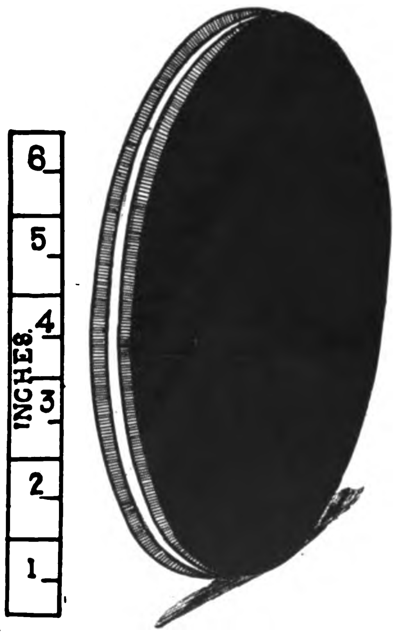

FIG. 1

A single cell of the oxide film lightning arrester consisting of a ring of porcelain with two circular steel disks, one spun on each side of the porcelain and insulated by the porcelain. The inside of the ring of porcelain between the plates is filled with peroxide of lead.

forms, producing a film of insulation which stops the current. This method of film formation over any large area is rather irregular, and of course the oxide is not used in such a fashion in the commercial arrester. Instead of this formation of litharge film any insulating film may be put on the electrodes initially. As insulating film spread on the metal plates there have been used thin layers of the following; glass, water glass, halowax, cloth, balsam, shellac, oil, paints, lead paints, varnishes, and lacquers of all available kinds. In all cases the results are sim-

ilar, varying only with the voltage at which puncture of the film of insulation occurs.

The foregoing statements define the principle of the commer-

FIG. 2

Shows the disassembled parts of a single cell of the oxide film lightning arrester. From left to right are a steel disk spun on a ring of porcelain, a pile of brown peroxide of lead, the other steel disk and an asbestos washer.

cial oxide film arrester. Fig. 1. It comprises two sheet metal electrodes, set about 0.5 in. (12.7 mm.) apart, one or both covered with a thin insulating film and the space between the plates

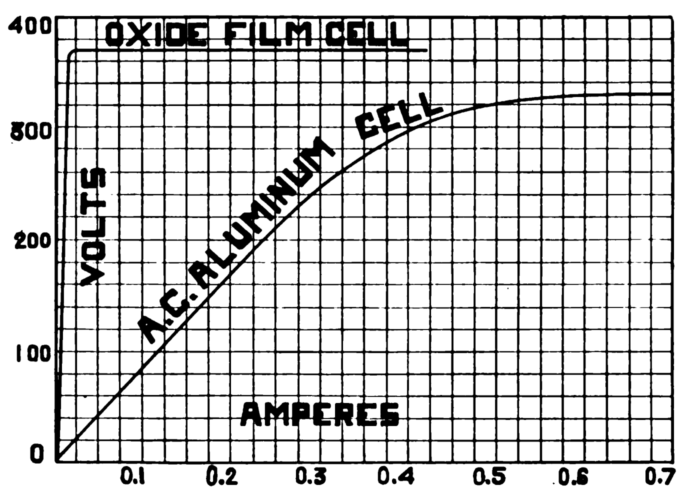

FIG. 3

The comparative volt-ampere characteristics of the oxide film cell and the a-c. aluminum arrester cell. The oxide film has only a few milliamperes of leakage current up to the critical film voltage when the film gives way more suddenly than the film in the aluminum cell. The critical voltage of the oxide film can be made approximately as low as the hydroxide film on the aluminum cell.

filled with some such substance as that described above, as, for example, lead peroxide. Fig. 2 shows the disassembled parts of a single cell. At a permissible voltage of 300 volts per cell the insulating film prevents any appreciable current flowing under

normal conditions. As soon as the voltage rises slightly above normal the film punctures in one or more microscopic points, the lightning charge meets with practically no resistance and flows to earth. Fig. 3. The dynamic current starts to follow but because of the fact that the insulation was punctured in such

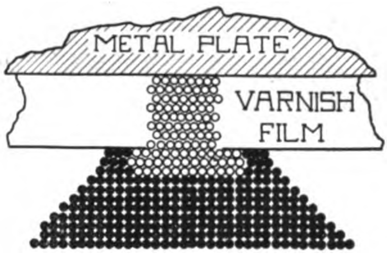

FIG. 4

A magnified, imaginary representation of one of the films on one metal plate. As shown the film is punctured by a spark and filled with a litharge plug which is represented by the open circles. The cross-section in the discharge path, a short distance away from the metal electrode, is sufficiently expanded to make the current of low enough density not to heat the peroxide to a temperature of reduction to litharge. The peroxide is represented by the solid dots and only those in the path of the discharge are shown. At the other electrode, not shown in this magnified diagram, a similar effect may be taking place although there is a difference between the positive and negative crators.

fine points, the current density near these points is exceedingly great. This results in a localized heating which speedily raises the temperature to a value sufficient to change to insulating litharge all the conducting peroxide in this minute path of the current flow in contact with the electrodes. The film conse-

FIG. 5

New electrode and also one from a cell having had passed through it several thousand discharges. The light colored plugs of litharge are plainly visible in the many spots on the surface of the plate.

quently reseals, stopping the further flow of dynamic current. This action is so rapid that its duration cannot be measured on an oscillograph giving two thousand cycles per second, that is to say, the action of resealing occurs in less than one four thousandth part of a second after the excess of lightning voltage has ceased. Fig. 5 shows the visible spots of insulating litharge plugs on the surface of an electrode.

This film can be made of litharge itself, as well as any of the insulating materials above named. For example, metal plates may be inserted in any of the well-known lead electroplating solutions, and thus a very thin lead peroxide film (measuring a few hundred thousandths of an inch) formed. By proper heating this will be changed to litharge and this form of electrode can be used. Peroxide may also be sprinkled over any metal plate and the plate heated, which will reduce the peroxide to litharge. Again, the metal chosen for the electrode itself may be lead and if heated in the air a thin film of litharge will be formed on the surface. Again, an aluminum electrode may be put in any of the common electrolytes, and a thin aluminum film be built up. This may be used with the peroxide powder. Of these methods of forming the film the most preferable is by dipping in varnish or lacquer highly burnished surfaces of brass, steel, or copper, and is consequently used in the commercial arrester. The ohmic resistance of the arrester during discharge is quite low (less than 1 ohm per cell). Thus, when the insulating film is punctured the arrester offers very slight impedance to the flow of energy at abnormal voltages.

There is a certain range of voltage necessary to pierce any given insulation. The exact voltage depends not only upon the thickness of the insulation and its dielectric strength but also on the relation of the dielectric spark lag to the duration of the super-spark potential and the frequency of alternations of the transient surge.

If an arrester is to give protection of insulation in shunt with it, the arrester must relieve the abnormal electric pressure before damage is done to the insulation. Although tests are frequently made with the arrester and the insulation it is to protect in parallel, a more convenient method has been standardized and is known as the equivalent sphere gap test. Both the insulation and the arrester are compared by comparing each to the equivalent sphere gap.

The equivalent sphere gap of the oxide film arrester may be analyzed, as in other cases, into separate and distinct parts. First, there is the equivalent sphere gap of the main gap in series with the cells. Second, the equivalent sphere gap to initiate a discharge through the insulating film on the plate surface of the cell. Third, there is the equivalent sphere gap of the resistance drop of the current discharging through the powdered peroxide in its path. Fourth, there is the equivalent sphere gap of the inductance of the arrester.

Commenting on these factors in their relation to this arrester, the main gap is itself a sphere gap which has the fastest spark of any practical gap. The gap setting, like that of the aluminum arrester, is only slightly above that of the normal voltage of the circuit.

The equivalent sphere gap of the film is several times greater than the thickness of the film because solid material has a greater dielectric spark lag than air, but with this multiple of the thickness of the film the equivalent sphere gap is still low. Since peroxide is a good conductor, the series resistance in the path of the discharge is insufficient to give an undesirable voltage drop. As to the inductance of the arrester, it has a minimum value due to the fact that each cell is only 0.5 in. long, as shown in Fig. 1, and these cells are placed one on top of another. In other words, the total length of the arrester (which constitutes the inductance) is short as compared to the necessary length of conductor from line to earth.

One of the obstacles that had to be overcome in the making of this arrester was the increase in the resistance after a great many heavy discharges had passed through it. The predominant reason for the increase seems to be explained by the following theory. The current passing through this small puncture in the film heats up very rapidly not only the powder but also the air contained within the interstices of the powder. The particles are thereby thrown out of contact with each other, thus producing a fluffiness. The decrease in the number of contacts decreases the actual cross sectional area of conduction' hence increases the resistance. This raises the equivalent sphere gap. This action is accelerated, of course, by the giving off of the oxygen itself evolved in the reduction from lead peroxide to the lower oxide. If, however, this same arrester be violently jarred or the filling powder be compressed, or any other method utilized to restore the particles to their previous intimate contact, the equivalent needle gap will fall again. While increased fluffiness appears to be the predominant cause of change of the equivalent sphere gap, the increased thickness of the film of litharge at the point of puncture of the film is finally a factor of moment. The total area of the film must be sufficient to give a reasonable number of years of life to the arrester. There are other factors relating to the details of manufacture which give a limited degree of control over this change in equivalent sphere gap.

In all the commercial oxide film arresters used for alternating

current the power factor is nearly unity. For special purposes however, the power factor can be made anything desired from 10 per cent. to unity. This is obtained by combining with the conducting oxide other non-conducting materials. This principle has been made use of for condensers but it has not been found desirable to incorporate it in the arrester.

To summarize—an arrester operating under a new principle has been made which comprises in essence one or more metal electrodes covered with an insulating film, and separated by a conducting powder, which has the peculiar characteristic of becoming a non-conducting powder upon the application of heat. Voltage higher than that which can be withstood by the insulating film punctures it in one or more points of about 0.005 cm. diameter. Dynamic current flowing gives a high current density in the conducting powder adjacent to these punctures which in turn heats it up rapidly, reducing the powder to a non-conductor, and sealing the holes in the film. The powder being a poor heat conductor localizes this action, so that very little more powder is reduced than is actually necessary to seal up these minute punctures.

The critical spark voltage and that part of the equivalent sphere gap controlled thereby is a function of the thickness and kind of material used for the film.

Comparison of the "Oxide Film" with Well Known Arresters

The earliest form of non-electrolytic film arrester was known as the dry aluminum arrester.* It was a direct attempt to utilize the dry film which forms on the surfaces of pure aluminum immediately after it comes in contact with the oxygen of the air. The hydroxide film is easily formed in electrolyte and on drying becomes a dry film which gives sufficient action to prevent a discharge up to a given critical voltage, depending upon the thickness of the film. The film can also be formed by a spark or arc of a conductor in contact with a plate. Naturally this conductor should be of a non-metallic nature. In the earliest form tried powdered carbon was used mixed with dioxide of manganese which gives a liberal supply of oxygen at the heated point.

One of the objects of the development of this arrester was to decrease the cost of manufacture and it was found with the new principle involved in the oxide film arrester, where the powder

* U. S. Patent, E. E. F. Creighton.

furnishes the film rather than the plate, that the aluminum could be replaced by a cheaper metal, such as steel, and, as already described, the initial film known in the early stages of development as the "paint skin" type could be furnished by a ayer of varnish. On first sight, knowing the extreme thinness of the hydroxide film on wet aluminum cell it might not seem that the dry cell would give the same general characteristics as the wet cell. But a comparison of the volt-ampere curves shows the same general characteristics. For a-c. voltages of 300 volts average per cell the current in the dry cell is of negligibly small value up to 40 milliamperes. The power factor is nearly unity and the current flow is due to very slight leakages through the films. In the case of the aluminum electrolytic cells there is an equivalent condition, the d-c. leakage current of the order of one milliampere being due to leaks through the hydroroxide film. In the a-c. aluminum arrester the leakage current on the plate area used is much greater due to the destructive action of the alternating current on the hydroxide film. Furthermore, the wet cell with its thinner film is a condenser of appreciable capacitance which takes a charging current of about 0.5 ampere at 60 cycles. When the voltage reaches a certain critical value which is between 300 and 400 volts for the wet aluminum cell and between 300 and 500 for the oxide film cell (or higher if the paint film is made thicker) the current is allowed to pass freely through the cells, limited only by the ohmic resistance of the cell independent of the film. Since the oxide film arrester has no dissolution of the film, as occurs in the wet aluminum cell, charging is not only unnecessary but undesirable. This extends the use of the oxide film arrester to localities where there are no attendants.

Although the wet aluminum plate becomes frosted to an appreciable thickness by the passage of current in long use, the actual thickness of the film, as represented by the critical voltage, is not changed. In the oxide film arrester, however, the film less than one 1 mil thick (0.025 mm.) initially thickens up by the addition of successive spots of litharge for each successive discharge. This represents the wear on the arrester and limits its total life. Fig. 3 shows comparative volt-ampere characteristics of the oxide film arrester and the a-c. aluminum arrester. Since both of these arresters have a leakage current which wears the plates of the cells when alternating current is supplied, it is necessary, as previously stated, to place a spark gap in series with the cells. This spark gap is set at a value

slightly above the normal potential of the circuit so that nothing but abnormal voltages will cause a discharge.

The foregoing data show that the oxide film arrester has general characteristics closely like the standard aluminum electrolytic arrester. It has the obvious advantage which comes from being dry rather than wet, it will not congeal and needs no daily charging.

In making the characteristic volt-ampere discharge curves the oxide film arrester does not lend itself as readily to the test as the wet aluminum cell. While its critical film voltage is evident, the change from no conduction to full conduction is more sudden. Therefore, the discharge rate at double potential is best shown by throwing double potential on the cell and subsequently reducing the voltage to its normal value per cell.

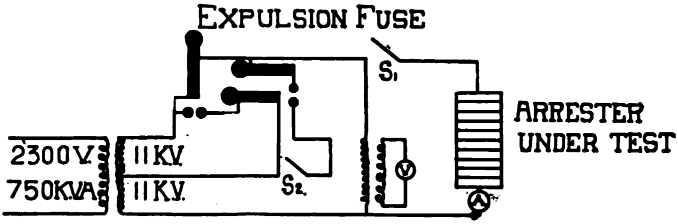

FIG. 6

Arrangement of three expulsion fuses which short-circuit gaps in the path of discharge to first throw double voltage on an arrester under test and then reduce the voltage to normal value by shifting the contacts on a transformer from full coil winding to half coil winding.

This gives a very considerable quantity of electricity through the cells and is a severe test.

In order to conveniently alter the voltage from double value to normal value the circuit is arranged as shown in Fig. 6. The object of the connections may be briefly stated: A transformer with two coils in series impresses voltage on the arrester and then the contacts of the arrester are automatically shifted to one coil giving half the voltage. A heavy pendulum closes switch *S*-1 and sets the oscillograph into operation. The full voltage on the transformer is thrown on to the oxide film arrester under test, marked *O-F*, which has a number of cells sufficient only for half the voltage of the transformer. In other words this throws double voltage on to the arrester and the heavy current passing through the cells causes fuse *F*-1 to blow. The operation of this fuse short-circuits half the transformer and throws the other half across the arrester. This is done by

means of gaps and fuses as follows: When the expulsion fuse *F*-1 blows, the conducting gases are shot into the open gap *G*-1 which closes the circuit through fuse *F*-2 to the mid-point of the transformer. This short circuit on half the transformer causes fuse *F*-2 to blow and the hot gases discharging from fuse *F*-2 close the gap *G*-2 which throws the mid-point of the transformer on to the arrester through the switch *S*-2 which is closed just previous to starting the test. These several operations occur with a rapidity depending upon the size of fuses used. It is possible

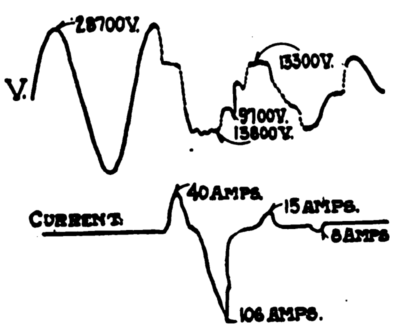

FIG. 7

Operation of an oxide film arrester on double dynamic voltage initially and its recovery on normal voltage. The upper record with a peak voltage of 28,700 volts shows the arrester connected to the circuit as the voltage wave starts to decrease on its third peak. The voltage immediately drops to the critical value of the cells—about 13,500. On the lower record the current is seen to rise to 40 amperes. On reversal of the voltage to 13,800 in the negative direction as shown by the upper record, the current as shown by the lower record rises to 106 amperes. The switching operations produce several electro-magnetic kicks as shown by the irregular voltage wave as it rises in the next cycle to 13,300 peak value. At this lower applied voltage the current in the series of cells, as shown by the lower record, is 15 amperes. In the subsequent half cycle the current rises only to 8 amperes. In the last half cycle of voltage shown, where the switching operation is complete, and the wave assumes its normal smooth form, the current in the cells is too small to be registered by the oscillograph. Its value is of the order of milliamperes. This figure is a copy of an oscillogram. The copy was made desirable by overlapping of the discharge on the two ends of the film.

by this means to throw momentarily 22,000 volts on an 11,000 volt arrester and note the character attending its discharge and recovery. Fig. 7 shows such an operation on an oxide film arrester. The initial discharge current is 40 amperes during the first half-cycle due to the point it strikes in the descending wave during the second half-cycle it is 106 amperes. After the third half-cycle the litharge film has so completely sealed up the path of discharge that the current is too small to show on the oscillogram. The leakage current with no series gap is of the order of a few milliamperes.

To be presented at the 34th Annual Convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 27, 1918.

THE OXIDE FILM LIGHTNING ARRESTER

BY CHARLES P. STEINMETZ

ABSTRACT OF PAPER

A short history of lightning protection of electric systems is given, as relating to the three successive types of electric circuits; the communication circuits, the power circuits of negligible electrostàtic capacity, and the high power circuits containing distributed capacity and inductance and capable of electric oscillation, leading to the three problems of discharging over-voltage to ground, opening the power current which follows the discharge and discharging so that no power current follows even for a fraction of a half wave. It is shown that these problems are solved by the spark gap to ground, by the use of non-arcing metals in the multigap arrester, which opens the circuit at the end of a half wave of current, and by the so-called "counter e.m.f." type of arrester, represented by the aluminum cell and the oxide film arrester.

It is shown that the necessity of taking care of recurrent discharges in high-power systems had led to the universal adoption of the aluminum cell arrester in such systems, in spite of its disadvantage of requiring daily attendance in charging, and of containing an electrolyte and oil.

In the oxide film arrester a type of arrester is presented which has the same characteristics and therefore the same advantages as the aluminum cell arrester, but does not require daily attendance and contains no liquids.

Its method of operation is explained, and its difference from the aluminum cell arrester; the dielectric film, which punctures under the discharge, and reseals after the discharge, is formed from the solid materials between the terminal plates, compressed PbO_2, and therefore no spontaneous chemical action occurs which dissolves the film, as in the aluminum cell, in which the film forms from the aluminum electrode, gradually dissolves, and therefore requires daily charging.

A short description of the construction of the oxide film arrester is given, a record of its operation in industrial service for over three years, and oscillograms showing the performance of this arrester under recurrents, oscillations and under high-power impulses.

THREE periods can be distinguished in the development of lightning arresters, corresponding to the three periods of the use of electricity:

(1) Electric circuits of negligible power, telegraph and telephone.

(2) Electric power circuits of negligible electrostatic capacity;

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d-c. lightning and railway, a-c. secondary and 2300-volt primary distribution.

(3) High-voltage electric power circuits, transmission lines, etc.

(1) In electric circuits of negligible power, such as telegraph and telephone circuits, a simple minute spark gap to ground afforded protection by discharging lightning to ground, and was sufficient until the recent years, when with the general introduction of electric power circuits the problem arose, in electric communication circuits to take care of crosses with power circuits.

(2) In electric power circuits, a simple spark gap to ground became insufficient for protection, since the power current, following the lightning discharge as arc, short-circuited the system and burned up the arrester. The problem then arose, to safely open the short circuit of the machine current to ground, through the lightning arrester, after the lightning discharge has passed, and to leave the arrester in operative condition to receive following lightning discharges.

Of the various devices developed heretofore, the magnetic blow-out lightning arrester still is used in direct-current railway circuits.

The first scientific investigation of this problem, is recorded in the paper[1] by A. J. Wurts, presented before the A. I. E. E. at the meeting of May 1894. Since that time all lightning arresters for alternating-current power circuits of negligible electrostatic capacity are based on the multigap principle between non-arcing metals, whatever constructive forms the arrester may assume—as the present compression chamber lightning arrester. The multigap arrester operates on the principle, that the lightning discharge over the multigaps closes the circuit to ground, but the power arc following the discharge extinguishes at the end of the half wave of the alternating current, as the non-arcing character of the gaps does not permit the reverse current of the next half wave to start. The multigap arrester thus short-circuits for a part of a half wave. It obviously is suited only for alternating currents.

For years difficulties were met with the question of resistance; without series resistance, in large systems the short-circuit power

1. TRANS. A. I. E. E., 1894, Vol. XI, p. 337, "*Discriminating Lightning Arresters and Recent Progress in Means for Protection Against Lightning*", by A. J. Wurts.

even of a part of a half wave may be sufficient to disable and destroy the arrester, while the use of a series resistance, while limiting the power current and thereby protecting the arrester, also limited the discharge capacity and thereby reduced the protection. This problem was solved by the use of multigaps shunting the series resistance, so that moderate discharges passed over the resistance, while high power lightning discharges found a path without series resistance, over the shunted gaps, and at the same time, the shunting resistance made the power arc at the shunted gaps unstable and thus assisted in the extinction of the short circuit at the end of the half wave.[2]

(3) As soon however, as circuits came into use, which had considerable electrostatic capacity, such as high-voltage transmission circuits, extended underground cable systems, or lower voltage circuits (including generator circuits) inductively connected with such circuits, the multigap arrester failed by frequently, or even usually destroying itself by the discharge, burning up.

In such circuits, oscillations between capacity and inductance may occur, started by a lightning discharge or any internal disturbance such as switching etc., resulting in recurrent high frequency oscillations, of which the arcing ground on a transmission line is typical and probably best known. With such continual discharges, often several per half wave, the multigap arrester short-circuits at the first oscillation, for the remainder of the half wave, and while the multigap functions properly and opens the short circuit at the end of the half wave, the oscillation of the next half wave again short-circuits, and so on, so that the effect is that of a continuous short circuit, and no lightning arrester, no matter how large, can dissipate the short-circuit power of a big system for any appreciable time.

For such systems, in which recurrent high frequency oscillations, as arcing grounds, may occur, a lightning arrester is necessary, which does not short-circuit the machine current even for a fraction of a half wave, but merely discharges the over voltage, the oscillation which, however high in voltage it may be, is small in energy compared with the short-circuit power of

2. See A. I. E. E. TRANS., 1907, Vol. XXVI, p. 425," *Protection Against Lightning, and the Multigap Lightning Arrester*" by D. B. Rushmore and D. Dubois.

the system, as it represents only the stored energy of capacity and inductance. The only arrester of this character heretofore was the electrolytic, or aluminum cell lightning arrester, developed by E. E. F. Creighton, J. L. R. Hayden, F. W. Peek and others. It acts towards an over-voltage discharge like a counter e. m. f. equal to the normal circuit voltage, and the discharge current passing through the arrester thus is the short-circuit current of the over voltage, while the normal machine voltage does not discharge, is held back and not disturbed. The aluminum cell arrester thus can discharge continual disturbances, over-voltage oscillations occurring at every half wave, for a considerable time, half an hour to several hours, before it is endangered by the temperature rise due to the accumulated energy of these discharges.

The aluminum cell arrester comprises a series of cells—usually conical and stacked into each other—of aluminum electrodes with an electrolyte, of which neither the salt nor its ions appreciably dissolve alumina. In "forming" the cell, by an alternating current passing through it, the electrodes are coated by a thin non-conducting film of alumina, which grows in thickness until it holds back the impressed voltage. Any over-voltage punctures this film, but the current passing through the puncture holes, again forms alumina and closes the holes. Thus the aluminum cell acts like a self repairing electrostatic condenser of a disruptive strength equal to the impressed voltage: about 250 to 300 volts per cell.

The practical experience of the last ten years has proven the aluminum cell arrester as the only type capable of affording protection in modern high power circuits, and proven this so conclusively, as to lead to its universal adoption in such circuits in spite of the inconveniences incident to the need of daily attention in charging, the use of a liquid electrolyte, and the difficulty of testing the arrester without taking it apart, except by watching the appearance of the charging arc, or measuring the charging current.

These inconveniences incident to the aluminum cell arrester were well realized however, and as soon as the minor troubles met with the aluminum cell arrester in the early years had been overcome engineers went energetically to work on the problem of developing a lightning arrester of the characteristics of the aluminum cell arrester, but which does not require any attention

beyond that given to every apparatus in a well managed system, that is, an occasional inspection, at least once or twice a year.

Numerous researches were made by the engineers whose splendid work I here acknowledge: Messrs. H. D. Brown, E. E. F. Creighton, Crosby Field, V. E. Goodwin, J. L. R. Hayden, N. A. Lougee, and G. B. Phillips. Some of these researches have not yet led to results ready for communication, but I am glad to present to you here as the result of the work of these men, and more particularly of E. E. F. Creighton, Crosby Field and N. A. Lougee, in the *Oxide Film Lightning Arrester* a new type of lightning arrester, which has all the characteristics and advantages of the aluminum cell arrester, but does not require any charging and thus requires no special attention, contains no liquid electrolyte, no inflammable material, and like the aluminum cell arrester, can be located outdoors as well as indoors.

The oxide film arrester, like the aluminum arrester, acts like a counter e. m. f. equal to the normal circuit voltage, freely discharging any over voltage, but holds back the normal machine voltage. Thus the discharge is limited to the energy of the over voltage, as in the aluminum arrester, and like the latter, the oxide film arrester can continuously discharge recurrent surges, such as arcing grounds etc., without endangering itself, for a considerable time, sufficiently long to notice and eliminate the disturbance.

Compared with the almost entire absence of knowledge of lightning phenomena in electric circuits, under which Mr. Wurts had to work in developing the non-arcing metal multigap lightning arrester, our present knowledge of lightning phenomena is very great. Nevertheless, there are so many disturbances in large electric systems, which we cannot or only incompletely reproduce in our laboratories, that the final decision on the success, that is, the effectiveness and permanence of a lightning arrester, still is best given by the experience in industrial systems.

Therefore, after extensive laboratory tests had been completed and had proven the oxide film arrester as of the same characteristic as the aluminum arrester, but requiring no special attention, a number of industrial installations were made, and more added the next year and the third year. Now, however, when a considerable number of installations of these arresters, for voltages from 110 to 33,000, have been in successful operation, some for over three years, and have proven their protective value and

their permanence, I consider it desirable to bring the arrester to your attention.

Of the numerous tests made on the performance of the arrester, it may be sufficient here to give only two, by the oscillograms Figs. 1 to 4, showing the action on a recurrent oscillation, in Figs. 1 and 2, and on a single high power impulse, Figs. 3 and 4.

The tests, oscillograms Figs. 1 and 2, were made in the usual manner: a surge or continual oscillation was produced by a large condenser, connected to an alternating-current supply and discharging over a spark gap through an inductance. The latter was chosen so as to give a frequency of 1200 cycles to the oscillation, and thereby bring it well within the range of the oscillograph. This surge was impressed upon the apparatus to be protected, a transformer energized by another alternating-current circuit. Fig. 1 shows the oscillogram without protection of the transformer, and Fig. 2 the oscillogram with an oxide film cell shunting the transformer and thereby protecting it.

In Fig. 1, the lowest curve shows the voltage of the 320-volt 47-cycle power supply circuit of the transformer, with the oscillations superimposed on it, rising to surge peaks of 2800 volts. The upper curve shows the oscillating currents passing through the transformer, rising to current peaks of 40 amperes. The middle curve is absent, as no arrester is used in this test. In Fig. 2 however, where an oxide film cell is shunted across the transformer, the middle oscillogram shows the current oscillations passing through the arrester, with peaks of 35 to 41 amperes. The lower curve in Fig. 2 then shows again the circuit voltage wave impressed upon the transformer, with the oscillations cut down by the oxide film cell. This voltage wave, the lower curve in oscillogram Fig. 2, well illustrates the characteristic action of this type of "counter-e. m. f. arrester"—to which the oxide film arrester and the aluminum cell belong. The oscillation peaks are sharply cut off at a maximum voltage of 60 per cent above circuit voltage: the value for which the spark gap was set. As the result, the oscillations are very greatly cut down from the high values which they have in the unprotected circuit Fig. 1 (2800 volts), and become unsymmetrical. The half waves of oscillation in the same direction as the circuit voltage are greatly reduced, by the limitation of the voltage to 60 per cent above-normal, while the reverse half waves—which lower the instantaneous circuit voltage— are less affected. Corresponding thereto the discharge current through the arrester, the middle oscil-

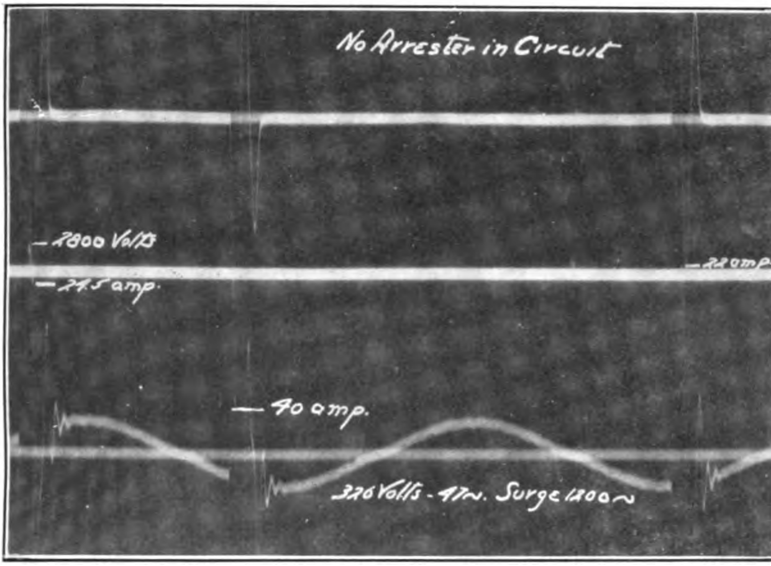
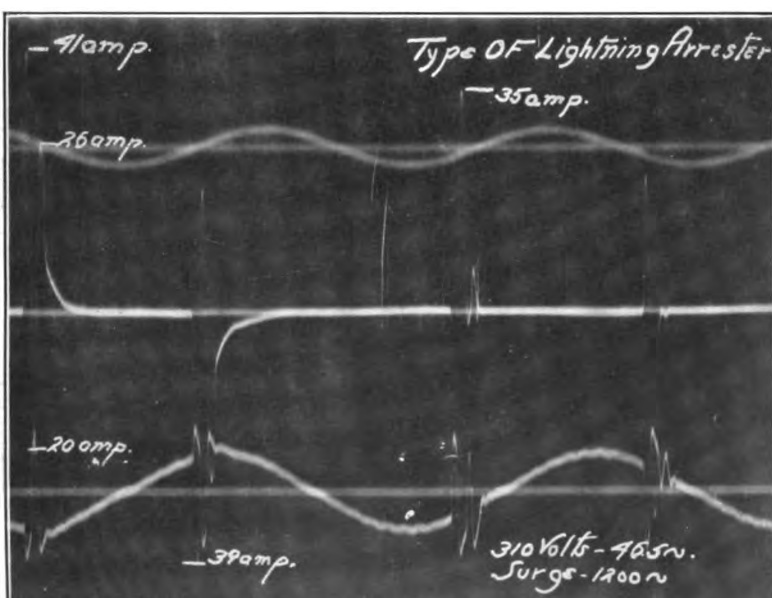


FIG. 1—SURGE DISCHARGE AS IN FIG. 2—NO ARRESTER IN CIRCUIT

Top vibrator—current through transformer.
Bottom vibrator—circuit voltage.



[STEINMETZ]

FIG. 2—SURGE DISCHARGE THROUGH ARRESTER CELL

Top vibrator—60-cycle timing wave.
Middle vibrator—current through arrester.
Bottom vibrator—voltage across arrester.

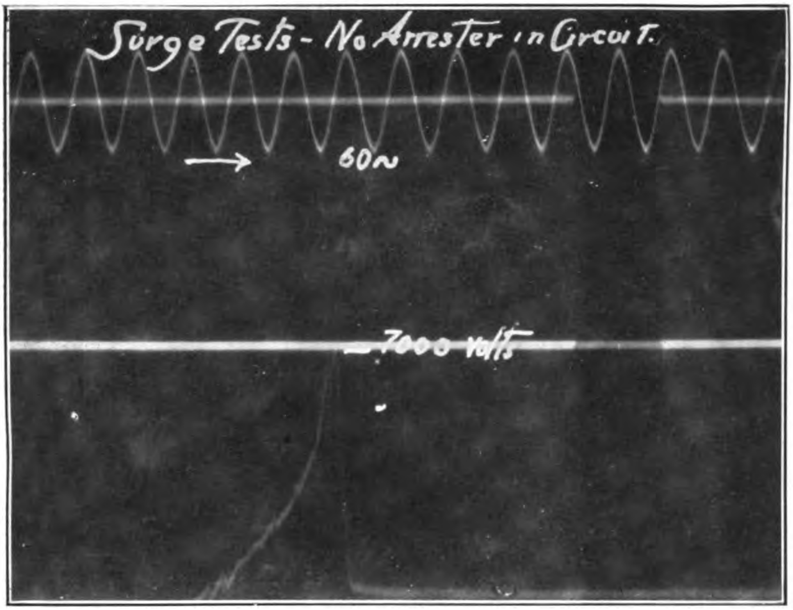
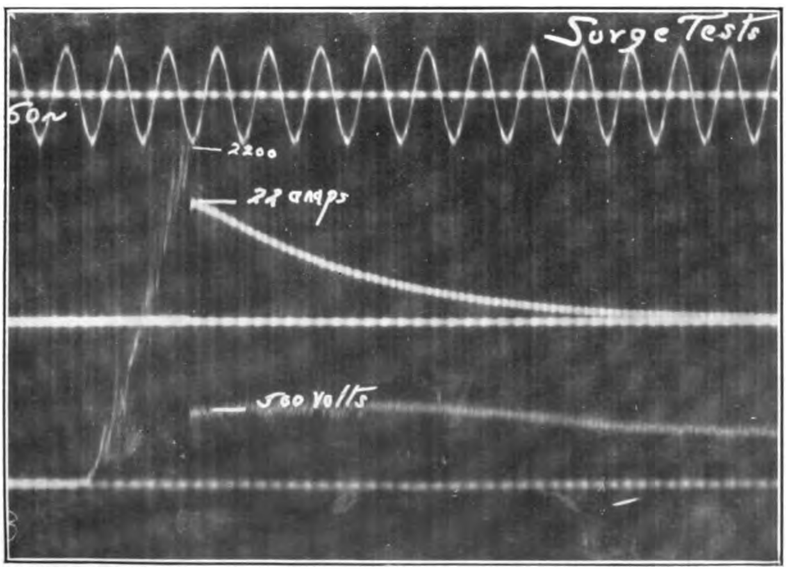


FIG. 3—SINGLE IMPULSE DISCHARGE—NO ARRESTER IN CIRCUIT

Top vibrator—60-cycle timing wave.
Bottom vibrator—circuit voltage.



[STEINMETZ]

FIG. 4—SINGLE IMPULSE DISCHARGE AS IN FIG. 3—ARRESTER IN CIRCUIT

Top vibrator—60-cycle timing wave.
Middle vibrator—current through arrester.
Bottom vibrator—voltage across arrester.

logram in Fig. 2, is unsymmetrical also: in the first and second oscillation of Fig. 2, the first and third half wave of oscillating voltage is cut off, and the first and third half wave of the oscillating discharge current therefore higher than the second half wave of the oscillating discharge, which latter corresponds to a ılf wave of oscillating voltage in opposition to the circuit voltage, therefore not raising the circuit voltage. The third oscillation of Fig. 2 happens to start with a half wave of oscillating voltage in opposition to the circuit voltage, and the first half wave oscillating discharge current through the arrester, in the middle curve, thus is smaller than the second half wave; the second half wave of the oscillation is cut down in the voltage and therefore gives the maximum discharge current, 35 amperes in this case.

This feature is well brought out by the oscillograms Figs. 1 and 2, due to the use of a different frequency, 60 cycles, for the power supplying the oscillator. This caused the successive oscillations to occur at different parts of the half waves of the 47-cycles circuit which was to be protected.

Fig. 3 and 4 then show the protective action of the oxide film arrester on a 550-volt direct-current circuit, against a single (non-oscillatory) impulse produced by opening a highly inductive circuit (railway motor). Fig. 3 shows on the lower curve the oscillogram of the impulse in the 550-volt circuit, rising to 7000 volts. The upper curve merely is a 60-cycle timing wave, to enable measuring the duration of the impulse. Fig. 4 shows the same circuit, with an arrester shunting it. The impulse voltage rises to the value for which the discharge gap of the arrester is set, in this case 2200 volts. Then the arrester discharges, and the voltage instantly drops back to normal, while a slowly decreasing discharge current through the arrester dissipates the magnetic energy of the impulse.

The cell of the oxide film arrester, shown in Fig. 5, consists of two circular metal plates as electrodes, which are kept apart by a porcelain ring, as shown in the figure. The space between the electrodes inside of the porcelain ring, is filled with the active material, lead peroxide PbO_2, which is put in under moderate pressure. This active material is a good conductor, but has the characteristic, that by the action of an electric discharge, it is converted in the path of the discharge, into a lower oxide, which is an insulator. Thus when an alternating current is passed through such a cell, the active material at the electrodes grad-

ually converts into a non-conductor, and forms a thin insulating film at the electrode. This grows in thickness, until it cuts off the further flow of current and holds back the voltage, about 250 to 300 volts per cell. Then only a small leakage current, of a few milliamperes, passes at normal voltage, but if an over voltage of any kind appears at the cell, the insulating film of lead oxide punctures and freely discharges through the lead peroxide, but in doing so, converts the surface of the lead peroxide in the path of the discharge into the lower non-conducting oxide, and thereby closes the puncture holes, repairs or reseals the film.

In manufacture, naturally, just as in the aluminum cell arrester, the insulating film is not produced after assembly of the cell by the slow process of passing a current through, but the film is put on before assembly, in the oxide film arrester, by dipping the plates in a suitable insulating varnish, which gives them a coating just thick enough to hold back the circuit voltage. Then after assembly, voltage is put on the cell for testing it and sealing any holes or defects which may exist in the varnish film.

In the oxide film arrester, the electrodes have nothing to do with the arrester action, and any suitable material can be used. First we used brass, but now use sherardized iron, the latter having a higher melting point and thus standing high power discharges, which would melt holes in the brass electrodes.

In this arrester, the action, which holds back the normal voltage but passes freely an over voltage, thus resides in the active material between the electrodes, and it is this material which forms and reforms the film. As this material is a solid, no chemical action occurs such as the gradual dissolution of the alumina film in the aluminum cell arrester, but the film remains intact permanently, and thus no daily "charging", that is, repairing of the film, is required.

A number of such cells, depending on the voltage of the circuit, are piled on top of each other, with a spark gap in series, and, for low and moderate voltages, incased as shown in Fig. 6.

As the cells are hermetically sealed, by the metal of the electrodes being spun over the porcelain separating ring, the cells can be installed outdoors as well as indoors, requiring in outdoor installation merely some protection by petticoats, as shown in Fig. 7, to keep the rain from short-circuiting the cells. Fig. 8 shows such an outdoor installation of a 33-kv. arrester, with three-phase stacks and the ground stack of cells, protected against the

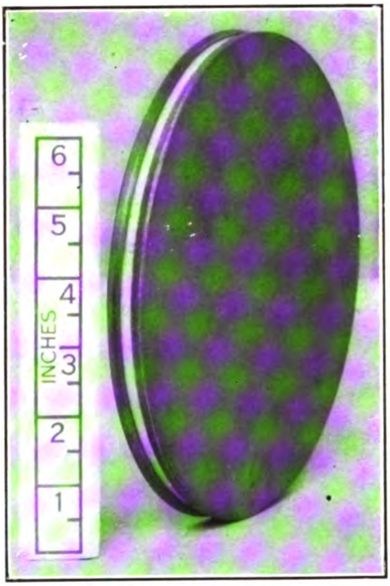
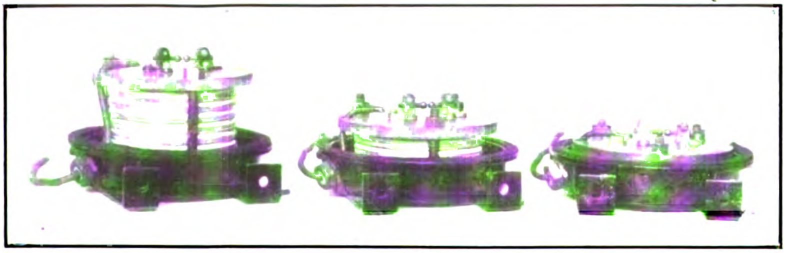
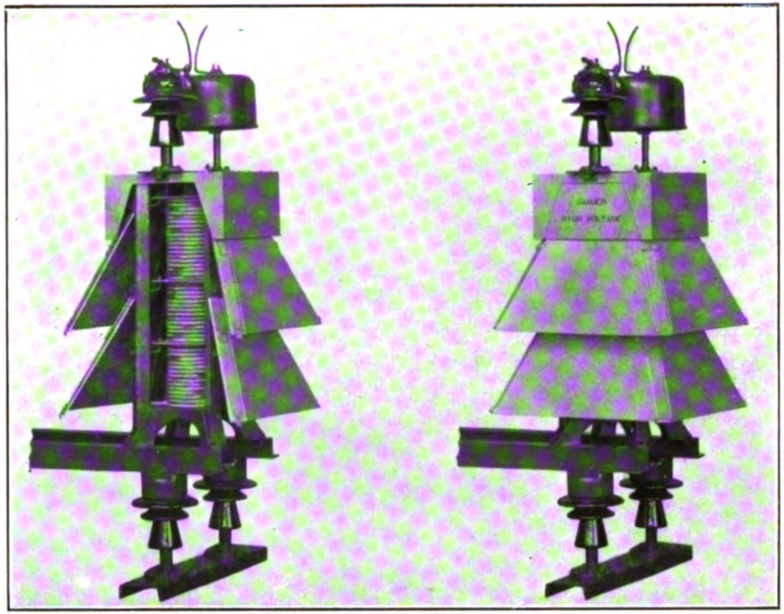


FIG. 5—TYPE "O F" LIGHTNING ARRESTER CELL



[STEINMETZ]

FIG. 6—TYPE "O F" LIGHTNING ARRESTERS WITH COVERS REMOVED RATINGS 325-650, 900-1350, 2100-2600-VOLT ALTERNATING CURRENT OR DIRECT CURRENT RESPECTIVELY



[STEINMETZ]

FIG. 7—PHASE SECTION OF 15,000-25,000-VOLT OUTDOOR TYPE "O F" LIGHTNING ARRESTER WITH SIDE OF HOUSING REMOVED TO SHOW INTERIOR ARRANGEMENT

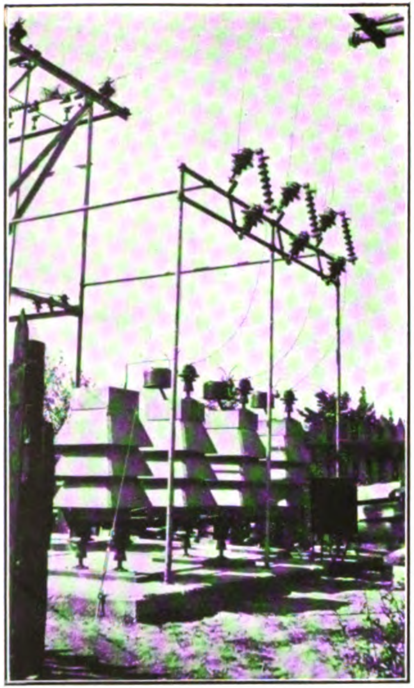


FIG. 8—TYPE "O F" LIGHTNING ARRESTER FOR OUTDOOR SERVICE INSTALLED ON A 33,000-VOLT CIRCUIT

weather by metal petticoats. Fig. 8 shows also the spark gaps on the line side of the arresters. They are protected sphere gaps, to give instantaneous discharge, with a horn attachment to allow the arc to flare up and thereby help in its extinction.

As well known, the plain horn gap has the disadvantage of requiring an appreciable —though a very short (microseconds) —time for discharge, and an extremely sudden high voltage, as a very steep wave front, thus may pass the horn gap and flash over elsewhere. Therefore in modern high voltage lightning arresters the horn gap is shunted by a properly proportioned sphere gap, the latter being "instantaneous" in its action. In outdoor use however, rain lowers the discharge voltage of the sphere gap, and thus requires a setting which gives a higher discharge voltage in dry weather than necessary. Therefore a protected sphere gap has been designed, which overcomes this disadvantage in the open sphere gap, and is shown in Fig. 8.

The need of using this spark gap in series with the arrester, is the only still remaining undesirable feature which the oxide film arrester shares with the aluminum cell arrester, the multi-gap arrester and other types. While by the work of Mr. F. W. Peek, on the time lag of electric discharges[3], the means have been given to make the discharge gap "instantaneous", that is, faster than any other discharge path over gaps or through insulation in the system, so that the arrester takes care effectively of any over voltage above its discharge voltage, it does not discharge voltages lower than the discharge voltage of its spark gap, even if these lower voltages may involve some danger to the system by their high frequency. Such low voltages, while they cannot endanger the main insulation between circuit and ground, may, if of sufficiently high frequency, lead to local accumulations of voltage across inductive parts of the circuit, as regulators, current transformers, end turns and coils of generators and transformers, and there cause damage by puncturing insulation between turns and causing internal short circuits.

Against these high frequency disturbances of moderate voltage, the only existing protection is the addition to the arrester of a capacity discharge path permanently connected from the circuit to ground. Such capacity path should be without resistance to flatten steep wave fronts, and contain a moderate series

3. A. I. E. E. Trans. 1915, Vol. XXXIV, Part II, p. 1857, *The Effect of Transient Voltages on Dielectrics* by F. W. Peek, Jr.

resistance, to dissipate high frequency energy and stop cumulative oscillations in their beginning. Before I leave the field of electrical engineering, I hope still to see an arrester, of the type of the oxide film or the aluminum cell, which has no spark gap, but is permanently shunted across the circuit, and thus capable of taking care not only of over voltages, but equally well of steep wave fronts and high frequency oscillations, even if of lower than the circuit voltage. Such an arrester then would give universal protection.

To be presented at the 34th Annual Convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 26, 1918.

AERIAL CABLE CONSTRUCTION FOR ELECTRIC POWER TRANSMISSION

BY E. B. MEYER

ABSTRACT OF PAPER

This paper deals with the problem of supplying high-tension electric service where conditions do not permit of the use of open wire or underground circuits.

The methods of overcoming difficulties incidental to providing for high-tension service are discussed in detail, together with a description of the types of cable used and methods of installation.

The experience of a large central station company operating several hundred miles of overhead and underground cable is given and the paper brings out the fact that the type of construction described may be used advantageously for both 13,200- and 26,400-volt service.

CENTRAL station companies have had to meet a number of difficult problems during the past three years but the most important has been that of supplying enormous power demands imposed upon them, particularly since the United States has become one of the allies in the European war.

On account of the rapidity with which most of the materials covered by war contracts must be delivered, industrial companies found that the building of isolated plants was out of the question, not only because of the time necessary for erection, but because of the low rates and excellent service furnished by utility companies.

At the present time the central station engineer in dealing with the customer has to provide for thousands of kilowatts rather than hundreds, which were the usual demands previous to the war.

These large demands have made it necessary to solve numerous operating problems in connection with the transmission system and to devise special methods of construction in order to serve the industries upon which the Government is depending to help win the war.

The Public Service Electric Company, which operates in 200

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municipalities throughout the State of New Jersey, supplies light and power to approximately 170 manufacturing plants engaged directly or indirectly on Government contracts. The material furnished under such contracts consists of high explosives, chemicals, shells, textiles, rubber goods, motor cars, castings, wire and cable, wireless apparatus, ships of various types, and many other accessories. In addition to this, Public Service Electric Company has contracts with the United States Government for furnishing light and power to Camp Dix, Camp Merritt, Raritan Ordnance Depot, Colonia Base Hospital, and the Quartermaster's Department located at the Port Newark Terminal. The supplying of these industries has made enormous demands on the generating system of the company so that at the present time about 80 per cent of the company's output in commercial power is for war work.

One of the special methods adopted by the Public Service Electric Company in meeting war time demands, was that of furnishing the customer with primary service by the use of aerial cable run on poles and supported by messenger wire, a type of construction similar to that used in telephone work.

This type of construction was first used by the company about seven years ago when it was found necessary to connect two large generating stations through tie feeders.

The matter of running overhead wire was considered but found impracticable because the line in several places would have to cross freight yards, trestles, and bridges, and the owners of these structures objected to open-wire high-tension lines.

Most of the section between these two stations was soil of a marshy character, through which it would have been impossible to run a duct line without the use of foundation piling.

It was therefore concluded that the use of aerial cable furnished the most satisfactory solution of the problem. In this installation ordinary lead-covered cable of the same type as that used for underground work was run on a pole line with 50-ft. (15.2-m.) pole spacing. To protect the sheath from mechanical injury there was applied a covering consisting of several layers of jute and marlin with an outer armor of soft steel tape.

The use of lead-covered cable for aerial work was found undesirable, however, because of the excessive weight of the cable and the fact that it could not be installed on standard pole line construction, and a special form of cable was developed to overcome these objections.

In Fig. 1 is shown the modified form of cable for 13,200-volt operation, which is made up with 7/32-in. (5.5-mm.) paper conductor insulation, a 3/32-in. (2.3-mm.) paper jacket and a 4/32-in. (3.17-mm.) reinforced rubber covering over the paper jacket. The reinforced rubber covering is similar in construction to that of the ordinary garden hose, being made up of several plies of fabric and rubber. The entire cable is saturated with rubber compound and covered with tape and a weatherproof braid, thoroughly impregnated with a waterproofing compound. For mechanical protection, the whole core is encased in an armor made up of galvanized steel tape. The use of this form of construction reduces the weight of the cable approximately 50 per cent and permits the use of lighter pole line construction.

The process of manufacture of the reinforced rubber covering

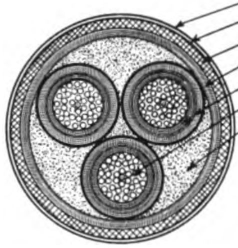


FIG. 1—REINFORCED RUBBER COVERED AERIAL CABLE

consists in calendering both sides of the cotton fabric, previously dried and waterproofed, with a 30 per cent Para rubber compound, so as to obtain a thorough filling of rubber, which, under the process of calendering, becomes partially vulcanized. The prepared fabric is then cut into tapes. These are applied to the electrical conductor in the usual manner, all contact surfaces and interstices being filled with a rubber cement. The insulated conductor is then dried under moderate heat. According to whether the reinforced rubber covering is applied over an insulating layer of rubber compound, or a layer of cambric or paper, the finished cable may or may not be subjected to vulcanization. In the latter case, the partial vulcanization of the rubber in the reinforced rubber is further advanced during the drying process and during leading in the case of leaded cables; otherwise further vulcanization takes place with aging and under service.

The finished material is perfectly homogeneous. Its specific insulating and dielectric constants are lower than those of rubber, paper and varnished cambric insulation, and for that reason, among others, it is preferable to combine a thickness of reinforced rubber with one of the other materials. By placing the reinforced rubber outside a thickness of a higher dielectric compound near the copper wire, the potential gradient is reduced so that the lower dielectric strength of the reinforced rubber does not materially decrease the total dielectric strength of the cable.

Many engineers have been of the opinion that paper insulated cable with the reinforced rubber jacket would not give satisfactory service when subjected to the heat of the summer sun, but in spite of the fact that the cable is exposed to the elements throughout the year the Public Service Electric Company has never experienced a service interruption through the failure of any of the aerial cable in use in the transmission system.

In Fig. 2 are shown several types of reinforced rubber multi-conductor cable with and without lead covering.

The following table gives approximate weights and outside diameters of three-conductor cables, insulated for 13,200 volt operation:

APPROXIMATE WEIGHT AND DIAMETER
OF THREE-CONDUCTOR, 13,200-VOLT AERIAL CABLE

Size	Weight per foot-lbs.	Dia. inches
No. 4	3.50	2.25
No. 2	4.05	2.41
No. 1	4.45	2.50
1/0	4.80	2.57
2/0	5.70	2.66
4/0	6.70	2.91
250,000 cm.	7.05	3.00
350,000 cm.	8.50	3.22

The principal advantage of aerial cable for tie feeder installations is that it makes little difference how many working lines are carried on a single pole line. Additional cable may be run, existing construction changed, transferred or repaired without taking out of service any line except the one on which the actual work is being done. Lightning discharges seem to have little effect because the messenger wire which carries the aerial cable is permanently grounded.

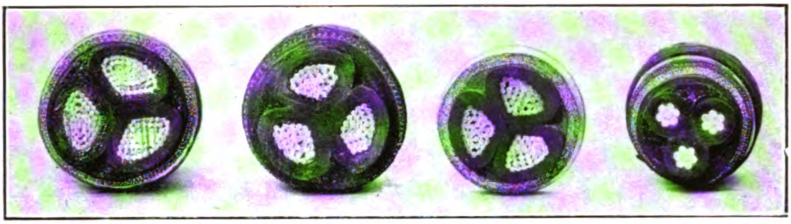
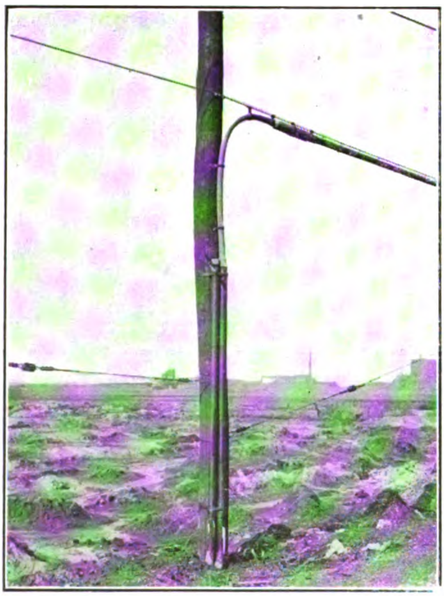


Fig. 2—Reinforced Rubber Multi-Conductor Cable

Fig. 3—Aerial Cable Line with Five 13,200-Volt Circuits



[MEYER]

Fig. 7—Connection Between Aerial and Underground Cable.

Fig. 3 shows a pole line carrying five 13,200-volt feeders. This line has been in operation for a period of over seven years without the occurrence of a single failure.

The usual aerial cable installation requires the use of Class B chestnut poles, with a normal spacing of from 90 to 100 ft. (27 to 30 m.). Where conditions make it necessary, sections as long as 150 ft. (45 m.) are permissible, but in such cases the adjacent sections should not exceed 130 ft. (39 m.). Sections longer than 150 ft. (45 m.) should receive special attention, and Class A poles should be used on long sections and at points of special strain. The location and frequency of guys is largely dependent on local conditions and can, in most cases, be decided upon by a competent line superintendent.

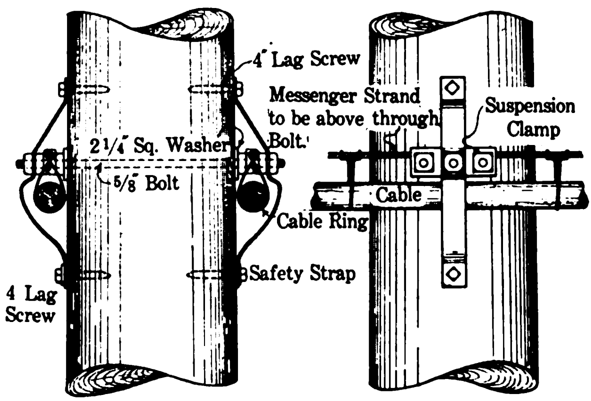


FIG. 4—METHOD OF SUSPENDING MESSENGER CABLE

Attention is called, however, to the fact that the stress at dead ends and corners is very great, frequently being as much as 25,000 lb. (11,339 kg.). These points of special stress need to be well guyed. Both the anchors and the guys should be designed with a factor of safety so high that the messenger will fail before the pole will pull over. In all cases it will be necessary for guy stubs to be reinforced by an anchor guy.

For the suspension of the messenger a double ended 5/8-in. (15.8-mm.) through bolt is recommended, as illustrated in Fig. 4. The use of a safety clamp is also desirable. This clamp serves the double purpose of reinforcing the through bolt and preventing the cable from falling to the ground in case the rings fail. Careful tests made on the method of suspension show that it will withstand the maximum loads to which it will be subjected.

The type of clamp used is similar to that used by the American Telephone and Telegraph Company, the size depending on the diameter of the messenger strand adopted. The clamp is designed expressly for construction of this character and is not built like a guy clamp which is designed to grip two strands instead of one. It affords a greater lever arm for the bolts to work upon in grasping the messenger and supports the messenger strand closer to the bolt, decreasing the bending moment on the bolt due to the weight of the cable.

The messenger strand should always be placed above the bolt in order that the weight of the cable will not be supported by the clamp. Various forms of cable rings may be used in supporting the cable on the messenger wire.

Where two or more cables are to be installed on a pole line,

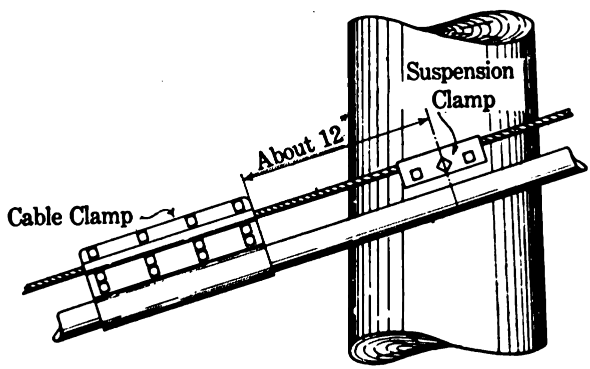


FIG. 5—CLAMPING CABLE TO MESSENGER ON STEEP GRADES

they are usually suspended in pairs, two from each through bolt. The messenger wire is extra strength 5/8-in. (15.8-mm.), seven-strand, galvanized, steel wire. The wire composing the strand should be free from scale, inequalities, splints or other imperfections, not consistent with the best workmanship. It is usual in purchasing galvanized steel wire of this character to have it conform to a specification covering the galvanizing. This is necessary as otherwise inferior grade wire might be obtained.

It is very important that the messenger wire be drawn as tight as possible, in order to prevent sagging when subjected to the weight of the transmission cable. If this is not done, an unsightly installation will result. After the messenger wire has been given its final pull and properly dead-ended, the placing of the aerial cable is the next step. In pulling the cable up to the

messenger wire it is very important that precautions be exercised to prevent mechanical damage or excessive strains which would tend to weaken or damage the insulation.

It is customary in aerial installations to ground the messenger strand. Where the soil is dry or soil conditions unfavorable for grounding, a ground connection should be installed at every second pole. Where the earth is damp and soil conditions are favorable, a ground should be installed at every fourth pole. In marshy ground and in places where conditions are particularly favorable, a ground at every eighth pole will be sufficient. Where possible, this ground connection should be well bonded to some metallic subsurface structure. If this is not possible, the standard artificial pipe ground should be installed.

It is also desirable that the steel tape on the cable be bonded to the messenger strand with bonding wire at every cable joint, as proper bonding is necessary in order to furnish the required protection against lightning. Where cable is run through trees and likely to be damaged by abrasion it should be protected by several layers of galvanized tape similar to that later described for use in protecting the joint.

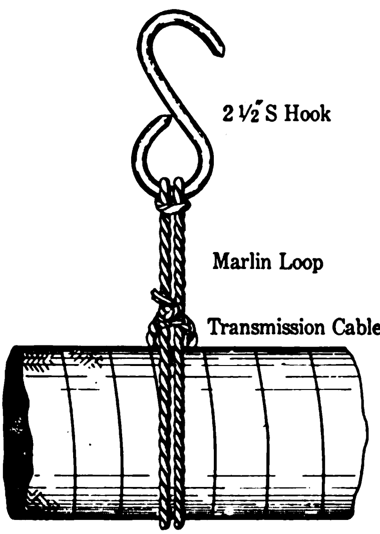


FIG. 6—METHOD OF FASTENING *S* HOOKS TO AERIAL CABLE

In Fig. 5 is illustrated a method of clamping the cable to the messenger wire. On steep grades where the angle between the cable and the horizontal is greater than 30 deg. the use of such a cable clamp is recommended. This clamp can be made up as required and should be used on every fourth pole. It is designed to take the greater portion of the down hill pull on the cable, which otherwise would be carried by the cable rings.

In erecting the cable, the first reel is set up in the usual manner and the cable run off to the first pole, at which is placed a sheave of approximately 12 in. (30 cm.) diameter, the top of the sheave being located about 5 in. (12.7 cm.) below the messenger wire. On the four or five succeeding poles similar sheaves or cable

rollers are placed, and in feeding out the cable 2.5-in. (6.35 cm.) "*S*" hooks, spaced 18 in. (45.6 cm.) apart, are fastened to it. These hooks are fastened to the cable with a small piece of marlin, made up in a loop knot, as illustrated in Fig. 6.

A lineman is stationed at each pole to change the "*S*" hooks from one side of the pole to the other, which process is repeated until the entire length of cable has been installed in place.

The "*S*" hooks, which were used as a temporary support, are now removed and permanent rings put in place. This is done by a lineman supported on a boatswain's chair, which is moved along the section supported by the messenger wire.

In running the transmission cable, either a motor truck, horses, hand or power winch may be used.

In the splicing of aerial cable, no special means are employed, but the usual precautions observed in the installation of underground cable must be followed. The jointing of any cable is more or less a matter of individual experience and great care must be exercised in all cases to exclude moisture. The work should be carefully done by a reliable and experienced workman and no splicing should be undertaken when weather conditions are unfavorable.

Each conductor of the cable is insulated with black bias-cut varnished cambric tape of a thickness of about 30 per cent greater than the machine applied insulation. Between each layer of tape, varnished cambric insulating compound is applied. After the individual conductors have been insulated a jacket of bias-cut black cambric tape, well painted between layers with an insulating compound, is applied to a thickness of 4/32-in. (3.17 mm.). Over the jacket of cambric tape several layers of the best grade rubber tape, 5/32-in. (3.9 mm.) in thickness, are applied and painted between layers with a high grade rubber compound. The completed joint is then covered with three or four layers of friction tape well painted with rubber compound. The joint is then ready for the application of a soft steel galvanized tape over which is finally applied an outer covering consisting of three or four layers of friction tape painted between the layers with a good grade of waterproof compound.

Where it is necessary to make connection from an aerial cable to an underground system a standard form of lead covered cable is used and installed in a lateral pipe as shown in Fig. 7. The joint between the underground and aerial cable is made up in the manner just described, and there is slipped over the joint a

FIG. 8—AERIAL CABLE ENTRANCE TO SUBSTATION

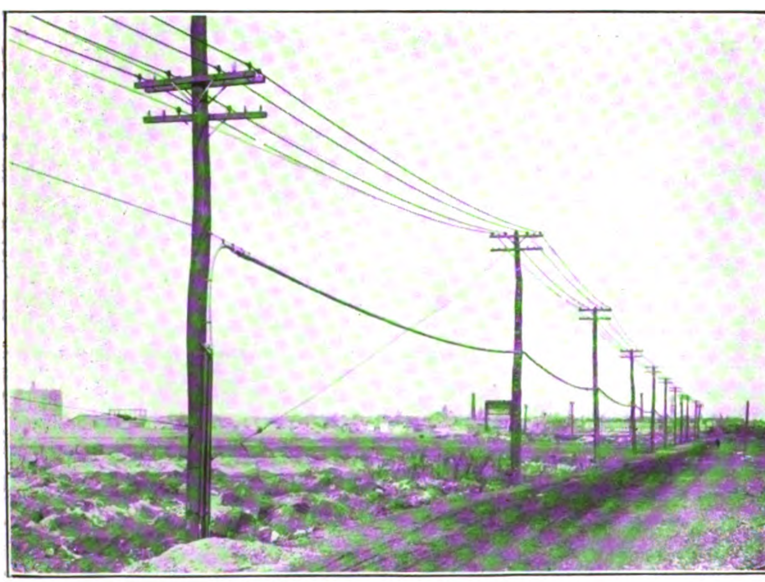


FIG. 9—26,000-VOLT AERIAL CABLE INSTALLATION [MEYER]

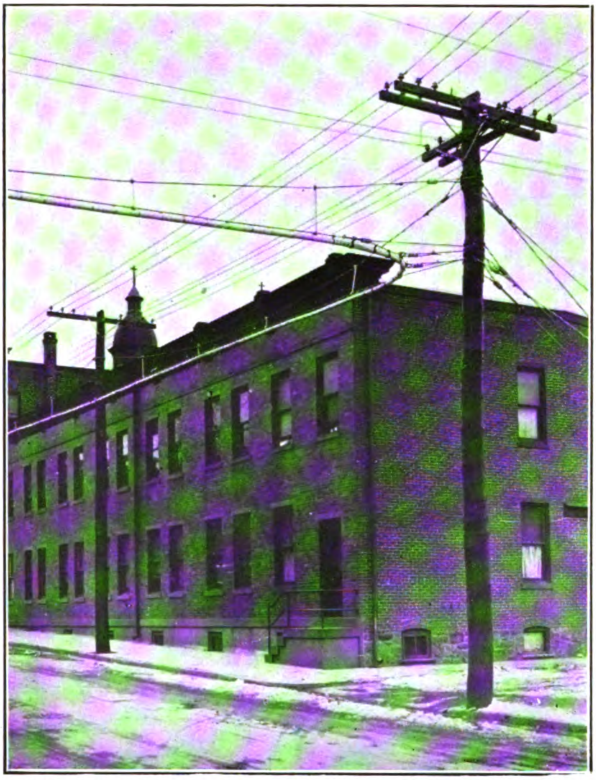
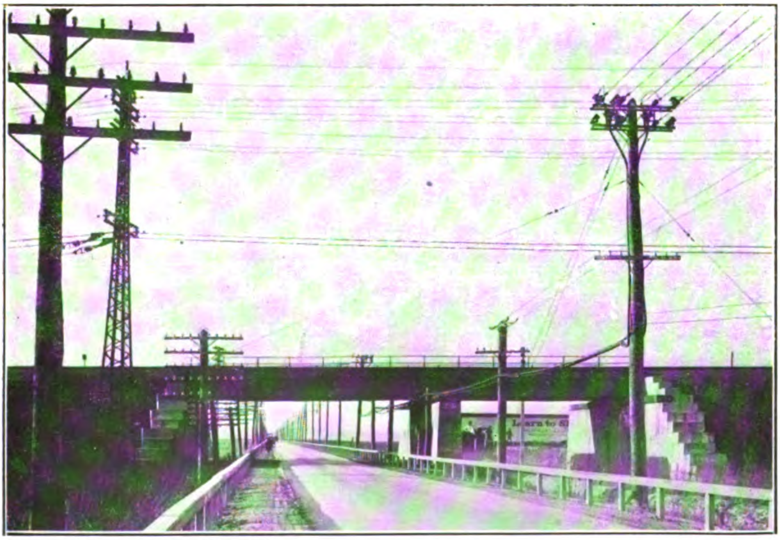


FIG. 10—CATENARY METHOD OF SUSPENDING AERIAL CABLE



[MEYER]

FIG. 11—26,000-VOLT CABLE CROSSING UNDER RAILROAD BRIDGE AND HIGH TENSION POWER CIRCUITS

lead sleeve, one end of which is wiped to the lead covered cable. The other end is well taped to prevent moisture from penetrating the cable.

Two aerial cables entering a power substation are shown in Fig. 8. In this installation iron pipe laterals are run up the pole and underground lead covered cable is spliced on to the aerial cable as just described.

While most of the existing circuits are operated at voltages under 15,000, the excellent results obtained with aerial cable has led the company to use this type of construction on all special work for operation at 26,000 volts.

In Fig. 9 is illustrated a completed 26,000-volt aerial cable installation. It should be noted that this method of construction permitted the erection of a high-voltage line without reconstructing the existing low-voltage open-wire distribution circuits.

To keep the cable in good condition it is necessary to paint it every four or five years with some form of insulating paint. This serves to keep the outside jacket from disintegrating and protects it from the action of the elements.

There is in service on the various transmission lines of the Company approximately 65,000 ft. (19,812 m.) of aerial cable operating at 13,200 volts and about 16,000 ft. (4,876 m.) either operating or in course of construction for 26,400-volt service.

Fig. 10 illustrates a catenary method of installing aerial cable. The line so erected was built to furnish 3,000 kw. to a customer who required service within a few weeks after the signing of the contract.

It was impossible within this short length of time to obtain the standard aerial cable with reinforced rubber insulation, and it was found necessary to take ordinary lead covered cable out of stock.

The erection of lead covered cable by the methods commonly used in installing aerial cable, on account of the weight and long pole spacing, would have resulted in throwing too great a stress on the messenger wire and lead cable. It was, therefore, decided to use the catenary form of construction so as to reduce the strain with the result that the transmission cable hangs perfectly level and without sag.

In Fig. 11 is shown an illustration of aerial cable crossing under a railroad bridge and electric railway power circuits. Open air potheads or line terminals are installed between the cable and the open wire transmission conductors. No protection in the

form of lightning arresters is provided as after a number of years of operation without failure from any source, the cost of the installation of arresters seemed to be unwarranted.

Aerial cable construction is somewhat more expensive than ordinary open wire construction but its cost is less than that of an underground conduit system. As the costs of the various types are so largely dependent on local conditions, no comparative estimates will be given here. In general, the cost of an aerial cable line is about midway between underground and open wire construction.

While this paper deals primarily with the use of reinforced rubber cables, there are numerous installations throughout the country where other forms of insulation have been used with satisfactory results.

It is not the intention of this paper to recommend exclusively the use of reinforced rubber insulation, but primarily to bring out the fact that aerial cable construction may be used advantageously for power transmission, where open-wire construction would be undesirable and the time and cost of underground construction would be prohibitive.

Where line extensions have to be made over marshy ground which would require the use of foundation piling for a conduit line, over private property such as railroad freight yards, trestles or bridges where very special overhead construction would be necessary, or on important streets on which open wires are not permitted, and subway construction would be expensive or impossible, aerial cable furnishes an ideal form of construction.

To be presented at the 34th Annual Convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 26, 1918.

APPLICATION OF THEORY AND PRACTISE TO THE DESIGN OF TRANSMISSION LINE INSULATORS

BY G. I. GILCHREST

ABSTRACT OF PAPER

The paper first gives a summation of the items that are apparently the main causes of pin-type insulator failures in service. Each item is thereafter briefly discussed and the opinions of operating men are cited.

A brief description is given of the method used to determine the form of the dielectric field about porcelain insulators under normal line voltage. Diagrams of the dielectric field and photographs of flash over tests of theoretical designs are shown. Thereafter, the necessary modifications of the theoretical designs, in order to meet operating and manufacturing conditions, are discussed.

In the latter part of the paper, diagrams and illustrations are shown of a proposed type of commercial insulator design which has been evolved by linking together the theoretical and practical phases of the problem. A comparison is then made between the older types of design and the proposed type, as regards the resistance of each to the conditions that cause failure of the insulator in service.

In conclusion, a summary is made of the advantages it is believed that the new type of design has over the present commercial insulator designs.

INTRODUCTION

USUALLY any design problem of engineering may be quite easily separated into two rather distinct phases. The one phase is termed "theoretical" and infers that the service experience, processes of manufacture, cost of materials, cost of manufacture, etc., are placed secondary in importance in the search of an ideal design. The other phase is termed "practical" and infers that the design has been evolved mostly from a consideration of service experience. It is generally conceded that a design evolved by either method may have certain advantages. The object of the following investigations has been to link together these two phases in a specific application, namely; the design of pin-type transmission-line insulators.

In order to save repetition, the present article will deal, for

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the most part, with laboratory tests of various new designs and the comparison of these designs with those now in commercial use. The theoretical elements of the problem which laid the foundation for the following developments are clearly given in two papers published in the 1913 A. I. E. E. TRANSACTIONS. One paper, by C. Fortescue, is subjected *The Application of Theorem of Electrostatics to Insulation Problems.* The other, by C. Fortescue and S. Farnsworth, is subjected *Air as an Insulator.*

Since an attempt will be made to deal with the practical and theoretical phases of the problem, two logical questions at once arise:

First, are the insulator designs installed in service at the present time satisfactory?

Second, can one type of design be developed that will be satisfactory in all localities?

The first question is answered by a resume of current engineering literature which offers convincing evidence that there is a field for improvement. A comparison of the flashover voltage versus overall dimensions and weight of the present insulator designs would seem to warrant an attempt toward uniformity. Furthermore, the divergence of certain characteristics of some designs from the average curves indicates that some of the designs must be far from efficient.

The causes of such chaos in the present day insulator designs are quite obvious and have been frequently stated. First of all, the progress in transmission engineering has been rapid. The expanding transmission companies demanded insulator designs which would offer a good factor of safety. There was no previous operating experience to use as a basis in new developments and consequently it was often necessary for the transmission engineer to propose his own design. Moreover, the majority of our present insulator types were designed when the electrical and mechanical characteristics of porcelain were less understood than at the present day. As a result, the type of design has fluctuated and various features were, at one time or another, accentuated as most important. That is, at one period a long leakage path was required, regardless of voltage distribution per shell from capacity current or leakage current; then again a high puncture voltage, than a high mechanical strength, and so on. Naturally, many mistakes were made and a large proportion of the older insulator designs have failed in service application.

Causes of Insulator Failures

The knowledge that certain insulator types have failed in service is of little value in the redesign of insulators unless actual conditions of service and cause of failure are known. Also, the cause of failure of a particular type in one locality should be compared to the cause of failure in other localities. Hence, before attempting to develop a new type of design, a study was made of available data on insulator deterioration and the opinions of operating engineers in various parts of the country were obtained.

From discussions with these engineers, from published data on insulator deterioration, and from observations of insulators that had failed in operation, it would seem that the following items are the main causes of pin type insulator failures:

1. Improper distribution of dielectric field.
2. Improper distribution of surface leakage.
3. Porosity.
4. Mechanical breakage.
   a. From handling.
   b. Mischievous shooting and stone throwing.
   c. Insufficient strength as a support.
   d. Brittle material.
5. Lightning.
6. Birds and animals short-circuiting line.
7. Unequal expansion of metal, cement and porcelain.
8. Internal stresses in material.
9. Defective batches.

Items 3, 4d and 9 are the problems in which the ceramic engineer is vitally concerned and will not be considered further in this paper. These items have doubtless been of great importance in the past but more scientific and painstaking factory control must minimize them in the future. ("Electrical Porcelain", *Electric Journal*, February and March, 1918, by T. A. Klinefelter and G. I. Gilchrest).

The manner in which these items have caused ultimate failure of certain designs are very briefly enumerated below:

1. *Improper Distribution of the Dielectric Field.* Failure to consider the electrostatic field distribution as regards every part of the unit has resulted in designs which have an unequal voltage distribution per shell even when the unit is dry and clean. When the rain sheds are closely spaced the air between them is ionized with the result that preliminary discharges take place before flashover. Parts of the unit in the dielectric field are,

thereby partially short-circuited and other parts overstressed. Flashover voltage will, therefore, be low in relation to overall dimensions. These conditions are usually augmented as the insulator becomes dirty and wet.

2. *Improper Distribution of Surface Leakage.* The most serious trouble from surface leakage is probably experienced on sections of line along the California coast, sections near Great Salt Lake, Utah, etc. Moreover, the climatic conditions of certain localities, especially where a "dry season" is followed by a "rainy season", augments the difficulty. For example, along the California coast the insulator surface gradually becomes coated with dirt during the "dry season" of the year. At night a strong breeze drives a fog containing more or less salt spray over the transmission lines. The dirt on the insulator surface then becomes moist and conducting and a rather high leakage current is often the result. Where wooden construction is used, charring of the wood at points of highest ohmic resistance may take place, resulting in the burning of pins and cross arms. The leakage resistance per shell of many of the older designs are such as to give a very uneven voltage distribution per shell under service conditions. Moreover, the voltage drop over the surface between closely spaced sheds often becomes sufficient to cause static discharges between them. The effective leakage surface of the insulator is thereby decreased and the arcing imposes an electrical impact on the insulator at the same time. Of course, this same trouble occurs on sections of lines near factories, steam railroads, cement mills, smelter plants, etc., to a more or less degree.

3. *Porosity.* The deterioration of porcelain insulators in service was given little consideration during the early days of transmission engineering. The majority of transmission engineers preferred an insulator having a porcelain body which offered a high resistance to mechanical breakage. As a consequence, the porosity of the material, which varies inversely to the mechanical strength as regards resistance to mechanical impact, was considered of secondary importance. The results that the condition has caused in service have been clearly presented before the Institute by Professor H. J. Ryan.[1]

4. *Mechanical Breakage.* Mechanical breakage has been a frequent source of annoyance, and has worked havoc in a number of ways.

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1. "*Ceramics in Relation to the Durability of Porcelain Suspension Insulators.*" A. I. E. E. TRANSACTIONS, Vol. XXXV, 1916.

(a) The deep thin sectioned sheds are easily broken in handling. This results in a loss of insulator units. What is of more importance, the danger of installing defective units is considerable, since many fine cracks may pass the usual construction crews' inspection.

(b) Some of the operating engineers, especially those located in the middle West, or near mining camps, claim that 80 to 90 per cent of the defective insulators removed from the line were first injured by rifle shooting or stone throwing.

(c) Many designs are not sufficiently strong as a support due to the thin sections of porcelain and small area under mechanical stress, or to the fact that the deep center shed necessitates a high pin. Such designs fail in service when unusual stresses occur, such as are caused by sleet storms, by poles giving way during freezing and thawing of the ground, or heavy rains, etc.

5. *Lightning*. It is generally conceded that a direct stroke of lightning will destroy any insulator that comes within its wake. However, some of the older designs, especially those having deep nner shells and heads of large diameter, were very vulnerable to any sudden impact voltage. In the first place, the impulse ratio (flashover voltage at high frequency divided by flashover voltage at normal frequency) of such insulators is rather high and in the second place the ratio between flashover voltage in air and puncture voltage under oil is comparatively low.

6. *Birds and Animals Short-Circuiting Line*. Some transmission companies have found it necessary to place shields on the poles in certain sections in order to prevent squirrels climbing the poles and short-circuiting the lines. In other localities it has been necessary to increase the height of insulator pins or the wire spacing in order to prevent cranes, eagles, etc., from short-circuiting or grounding the line.

7. *Unequal Expansion of Metal, Cement and Porcelain*. In many cases solid metal pins or heavy cast thimbles have been cemented into the insulator. Apparently the equal expansion of the metal, cement and porcelain has caused the cracking of the porcelain and ultimate failure of the insulator.

8. *Internal Stresses in the Material*. Corners of small radii and non-uniform sections of the porcelain shells have possibly produced internal stresses in the material during the manufacturing processes and these have developed cracks later on in service. Also, the relation between the shape of the shells in

the cemented area and the shape of the cemented area itself has been such as to allow the full effect of unequal expansion of the porcelain and cement which is caused by temperature changes or absorption of moisture.

Investigation of Dielectric Field

In the papers of Fortescue and Farnsworth, several insulator forms were evolved mathematically, and the dielectric field explored by means of an electrolytic bath. It was believed that the data from which these papers were written in conjunction with the available data of other investigators, of both analytical and experimental nature, afforded sufficient basis from which to formulate preliminary designs.[2]

After a careful summation of the data at hand, it seemed that the logical method of attacking the problem would be to have several theoretical insulator designs produced out of a usual commercial porcelain body. The dielectric field of these should then be investigated under a voltage of approximately the same value that would be impressed in service. Thereafter practical considerations, such as deterioration of the various commercial units in service, manufacturing limitations, etc., should be taken into account with the intent of arriving at a compromise between the theoretical and practical features.

Method of Determining Form of Dielectric Field

The dielectric field was determined by the following procedure: The insulator was fastened rigidly in a position such that the plane of the field to be determined extended horizontally. A piece of fullerboard was fitted over a half section of the insulator in this plane. In all cases the apparatus was so arranged that the cross-arm supporting the insulator was grounded as in service where steel construction is used. Finely divided asbestos was then sifted evenly onto the sheet of fullerboard, voltage at 60 cycles of the desired value applied, and the sheet was gently tapped until the particles had adjusted themselves. Permanent records were obtained by placing a sheet of photographic printing paper over the fullerboard, obtaining the field as above, and exposing the paper after the particles had become arranged.

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2. "Distribution of Potential about High Voltage Line Insulators," by C. T. Allcutt and W. K. Skolfield. *Journal of Electricity, Power and Gas,* June 17, 1916. *Electrostatic Problems,* by C. W. Rice. A. I. E. E. Transactions, Vol. XXXVI, 1917.

That the stronger portion of the field around an insulator was not disturbed materially by the presence of the fullerboard or the asbestos particles was proven by suspending a piece of finely drawn glass in parts of the field by means of a silk fibre supported by small insulated rods. As nearly as could be checked, the glass indicated the same direction of the field as the asbestos particles.

Theoretical Insulator Designs

The dielectric fields of five theoretical designs were determined. Wherever a customary transmission cross-arm and line-wire are used, there are two principal planes of the dielectric field which show the greatest difference, *i.e.*, the plane of the cross-arm and the plane of the line wire. These two planes are 90 degrees apart and in passing from one to the other the transition is gradual. During the investigation, records were taken of the dielectric field of these two principal planes and of a plane midway between the two. In this paper the diagram taken in one plane of the unit is usually shown. Diagrams of three planes of two designs are shown in order to illustrate the variations that occur. The plane in which the particular field was taken is indicated by the reduced top projection at the upper left portion of each figure.

Dielectric Field Forms and Illustrations of Theoretical Designs

Fig. 1 shows the field form of a bushing having dimensions of ring and rod chosen such as to give maximum breakdown voltage over the surface for the mean diameter of torus ring.

Fig. 2 shows a 60-cycle flashover on bushing of Fig. 1.

Fig. 3 gives the field form of a design using a confocal system of ellipsoids and hyperboloids of revolution.

Fig. 7A, 60-cycle flashover on shape shown in Fig. 3.

Fig. 4, field form between special metal cap and pin as might be used as terminals of a line insulator.

Fig. 7B, 60-cycle flashover between cap and pin as shown in Fig. 4.

Fig. 5, field form of line insulator without rain sheds.

Fig. 7C, 60-cycle flashover on shape shown in Fig. 5.

Fig. 6, field form of pin type insulator, the porcelain of which has a curvature similar to that of Fig. 5. However, the porcelain body is separated into three sections and metal rainsheds added to give wet arcing distance.

Fig. 7D, 60-cycle flashover on unit given in Fig. 6.

In Table I are given the length of path over the insulator surface between electrodes and the 60-cycle flashover voltage.

TABLE I

Shape in figure	Length of surface		Effective kilovolts flashover voltage		
	Inches	Centimeters	Total	Per inch	Per centimeter
1	4.25	10.8	87	20.4	8.1
7*a*	6.5	16.5	148	22.8	9.0
7*c*	8	20.3	115	14.4	5.7

From a consideration of Table I it is evident that a flashover value of between 20 and 23 kilovolts per inch (8 and 9 kilovolts per centimeter) of surface may reasonably be expected if the unit is designed with contours of the surfaces approximating the flow lines of the dielectric field. Of course, the flashover on the unit without rain sheds is somewhat lower, being 14.4 kilovolts per inch. The lower flashover on this unit is due to two conditions, *i.e.*, the porcelain surface does not follow the dielectric field in all planes and the small tie wire produces corona and subsequent static discharges at a relatively low voltage. Placing a static shield on the top of this unit increased the flashover voltage 18 per cent.

With the field form between cap and pin as given in Fig. 4, and the voltage values given above in Table I, theoretical insulator designs could be determined for such electrodes. Such designs should follow surfaces indicated on Fig. 4, as (*a*) and (*b*). The highest flashover voltage using a given weight of insulating material would thereby be obtained. Moreover, the flashover voltage of such a unit could be closely approximated if the electrodes have sufficient radius of curvature at points of contact with the insulating material and a good seal is made between the metal and the insulating material.

Modifications of Theoretical Design to Meet Operating and Manufacturing Conditions

Insulators based on such theoretical data would be excellent from the electrical and mechanical standpoints if they were to operate in clean, dry air. However, the commercial insulator must maintain the transmission system during the heaviest of

snow and rain storms. Moreover, it must have sufficient leakage distance to prevent flashover or even high power loss from surface leakage when the surface becomes dirty and wet.

The production of one-piece insulators for high-voltage service, although possible, would be costly. Also, the puncturing voltage of a one piece unit would be low for a given thickness, since the stress in an insulating material between metal electrodes of different potential varies as a logarithmic function. The separation of the unit into parts that are cemented together, more uniformly distributes the stress of the dielectric if the unit is properly designed. It also decreases the probability of complete failure of the insulator and facilitates factory production, lessening the cost of the commercial unit.

The use of a special cap would be desirable from a dielectric standpoint. However, the voltage characteristics under rain are the same whether the usual line and tie wire or a special cap are used. Moreover, the cost and ease of replacement, cost of construction, etc., favor the line and tie wire construction.

Proposed Commercial Insulator Design

With the above limitations of the theoretical designs and the causes of insulator failures in mind, the type of unit indicated in Fig. 8 was evolved.

Summed up briefly this type of design embodies the following features:

1. Surfaces *a* conform to the flow lines of the electrostatic field.

2. Surfaces *b* of the rain sheds conform to the equipotential surfaces.

3. Lines of mechanical stress are parallel to the electrostatic flow lines.

4. The leakage resistance per shell is about equal, being increased gradually from the head to the center shell.

5. Approximately equal capacity per shell.

Comparison With Older Designs

It is not possible to much more than indicate in the following discussion the methods employed to compare the proposed type of design given in Figs. 8A and 8B with the older commercial insulators. Samples of various commercial designs were produced and were subjected to rather thorough laboratory tests at the same time tests were made on insulators of the proposed design.

It should be noted that the insulators of the new type used in the comparative tests do not exactly correspond to the proportions of Fig. 8. In order to lessen the cost of investigation, insulator sheds of several diameters were obtained from one set of molds by trimming the individual shells before burning. This also accounts for the unfinished appearance of the edges of sheds, etc., in some of the experimental designs.

In the following comparison it is not assumed that the evolved design should be final in each detail. The main goal toward which work is being directed is uniformity of all the elements entering into the designs with the idea in view of arriving at a

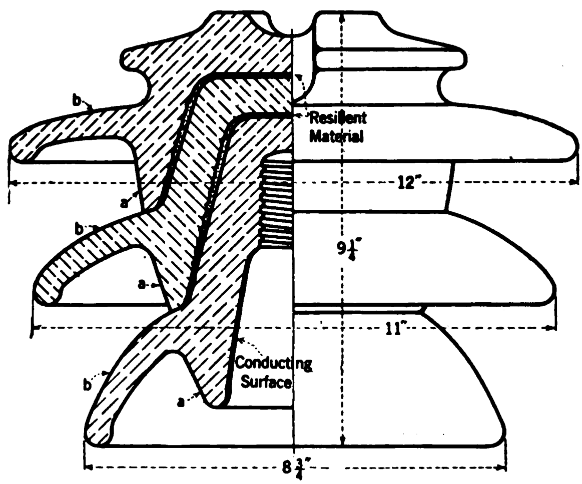

FIG. 8A—THREE-PIECE INSULATOR OF THE PROPOSED TYPE OF DESIGN—INSULATOR *A*

type of design which will be equally successful in resisting failure in service whatever the requirements are in that particular section. In the following comparisons the items causing failure in service are discussed in the order given at the beginning of the paper.

1. *Dielectric Field Distribution.* The shortest air path under electrostatic stress should be at least long enough to prevent overstressing of the air at any point. In the theoretical discussions referred to in the introduction it was proved that wherever porcelain and air are in series in a dielectric field the voltage gradient per unit distance through the porcelain will be ¼ to 1/5 the voltage gradient through the air. It is obvious that

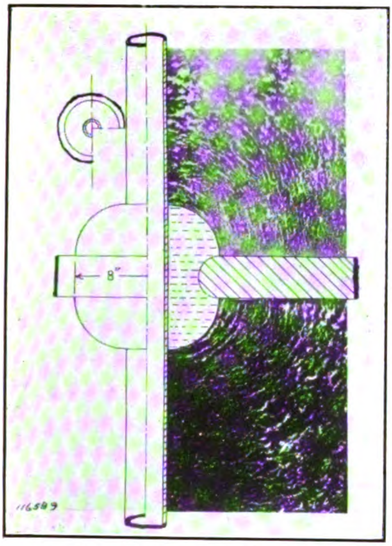

FIG. 1—DIELECTRIC FIELD ABOUT THEORETICAL BUSHING

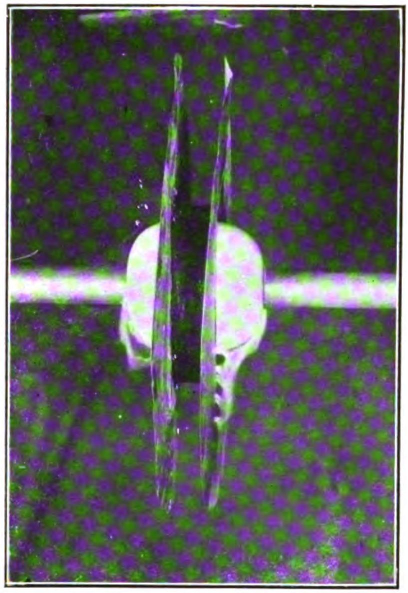

FIG. 2—60-CYCLE FLASHOVER BUSHING OF FIG. 1

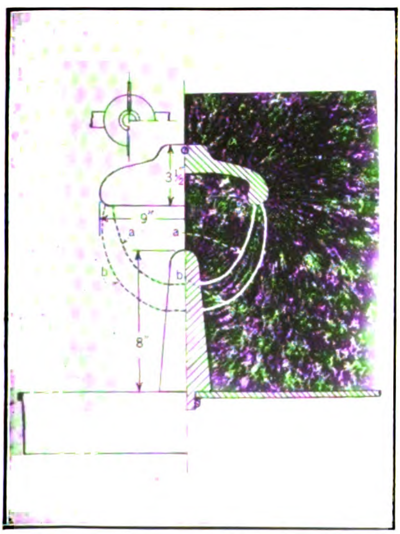

FIG. 4—DIELECTRIC FIELD BETWEEN METAL CAP AND PIN

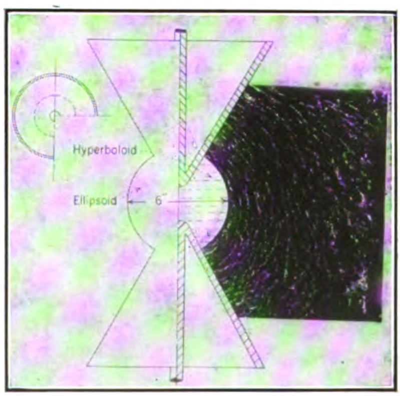

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FIG. 3—DIELECTRIC FIELD ABOUT THEORETICAL DESIGN USING CONFOCAL SURFACES OF REVOLUTION

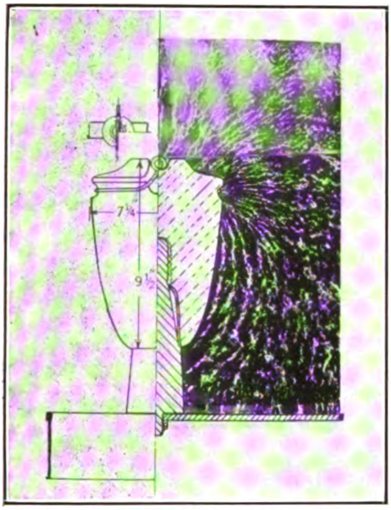

Fig. 5—Dielectric Field about Line Insulator without Rain Sheds

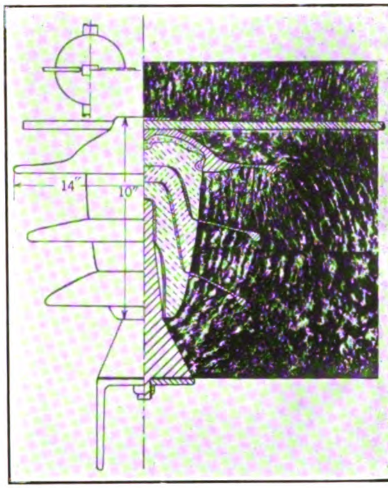

Fig. 6—Dielectric Field about Insulator with Metal Rain Sheds

[GILCHREST]

Fig. 7—60-Cycle Flashovers on Theoretical Porcelain Shapes

any thin section of air between porcelain sheds of a customary line insulator will be over-stressed even at the normal line voltage of the insulator.

In order to make a comparison of the dielectric fields of various insulators, their field forms were determined as in the investigation of the theoretical designs. It is believed that the following field forms and illustrations sufficiently indicate that many present types have not been designed with a full appreciation of the advantages of shapes that conform to the electrostatic flow lines in obtaining the most efficient distribution of the stresses in the dielectric field.

Fig. 9 (insulator *C*) gives the dielectric field of a unit of the type used in the early developments of high-voltage trans-

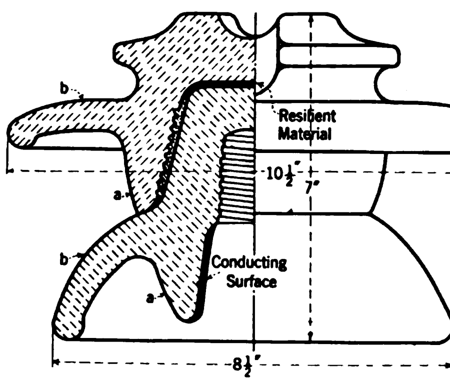

FIG. 8B—TWO-PIECE INSULATOR OF THE PROPOSED TYPE OF DESIGN —INSULATOR *B*

mission. The air between sheds just below the cement section is highly stressed. Because of the height of the pin in proportion to other dimensions of the unit the stress toward the base of the pin and the supporting cross arm is very low. Moreover, the third shell of the insulator is spaced so close to the insulator pin that it does not take its proportion of voltage stress when either dry or wet flashover occurs.

Fig. 10 (insulator *D*) shows the dielectric field of a three piece insulator of a somewhat more recent design. The center shed is better spaced than in insulator *C*. However, the air just below the cement sections is highly stressed and the short rain shed of the second shell gives an unequal voltage distribution at flashover, dry or wet.

Figs. 11, 12 and 13 (insulator *E*) show the dielectric field of a four-piece unit of comparatively recent design. The sheds of this design are more uniformly spaced, but the air between sheds just below the cement sections is highly stressed. The stress throughout the dielectric field of this unit is an improvement over the types *C* and *D*. However, the short second shed and protected fourth shed give unequal voltage distribution at flashover dry or wet.

Figs. 14, 15 and 16 (insulator *F*) show the dielectric field of a unit of the proposed design. The shortest air path between shells is sufficient so that the air is not overstressed at working voltage of the insulator or until flashover occurs. Moreover, the rain sheds are so spaced that each section of the unit takes its share of the stress at flashover, dry or wet.

Fig. 17 (insulator *G*) shows the dielectric field of a unit similar to insulator *F*, but having rain sheds of greater diameter. The diameter of the head of this unit is probably out of proportion and greater than would be most satisfactory for service. However, the stress in the dielectric is well proportioned and the voltage distribution per shell at flashover, dry or wet, is fairly well proportioned.

Fig. 18 (insulator *F*) shows the dielectric field of the insulator having upper surfaces of the rain sheds covered with a conducting paint. This field form which approximates the rain conditions indicates that the stress per shell on the unit during rain would be approximately equal. Moreover it indicates that the stress in the dielectric field is more uniform during rain.

Fig. 19 (insulator *F*) shows the dielectric field of the insulator when equipped with Nicholson Arcing Rings, and indicates that the most highly stressed portion of the field about the insulator is not changed. However, the most highly stressed portion of the field between the line wire and cross arm is now between arcing rings and flashovers would, therefore, occur between rings.

Fig. 20 (insulator *F*) shows the dielectric field when static shields are placed at the top and base of the insulator. This combination would give a very fine distribution of stresses in the dielectric but would be rather expensive commercially.

60-Cycle Flashover Tests

Flashover on most of the older insulator types is caused by the corona formation at the line and tie wires and the edges of the

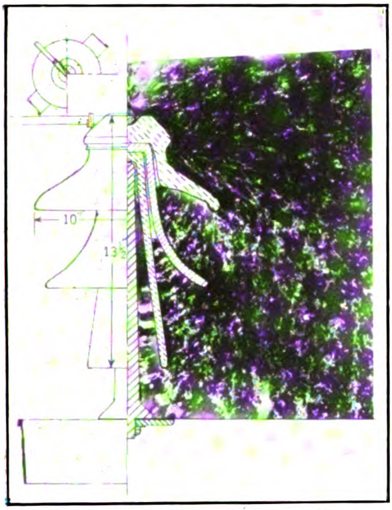

Fig. 9—Insulator *C*—Dielectric Field about Line Insulator of Early Design

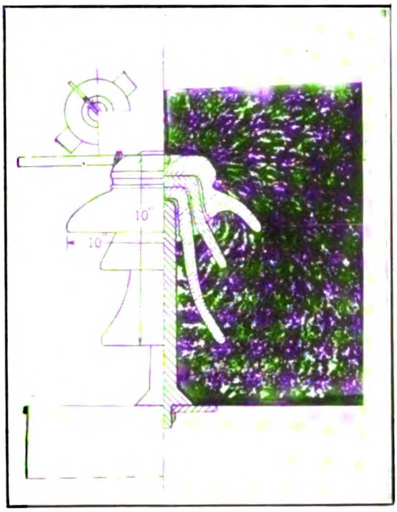

Fig. 10—Insulator *D*—Dielectric Field of Insulator of Fairly Recent Design

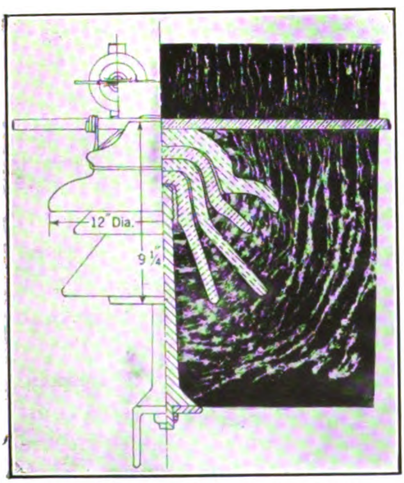

Fig. 11—Insulator *E*—Dielectric Field about Insulator of Recent Design

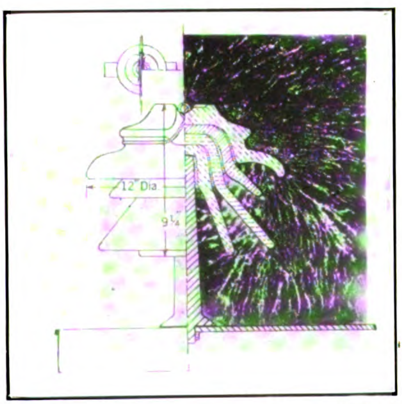

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Fig. 12—(See Fig. 24)

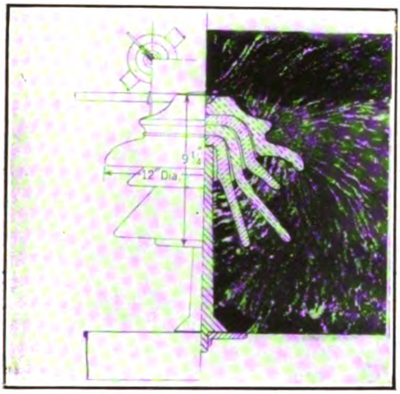

FIG. 13—(SEE FIG. 24)

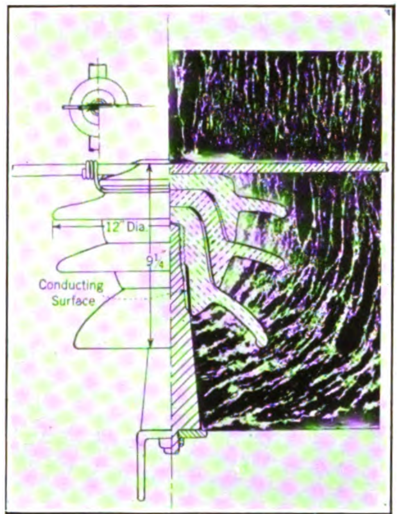

FIG. 14—INSULATOR *F*—DIELECTRIC FIELD ABOUT INSULATOR OF PROPOSED DESIGN

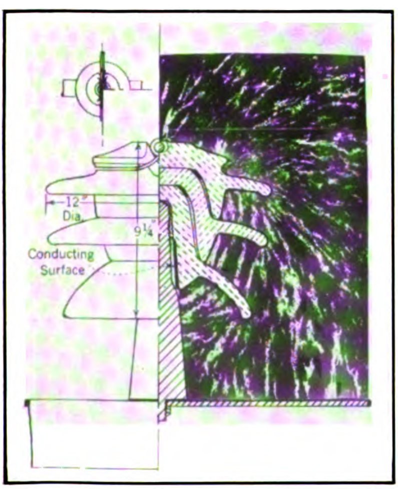

FIG. 15—(SEE FIG. 27)

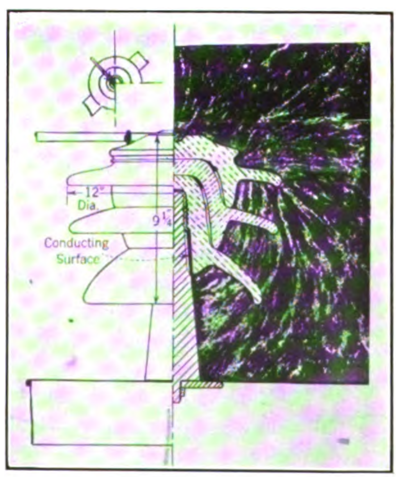

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FIG. 16—(SEE FIG. 27)

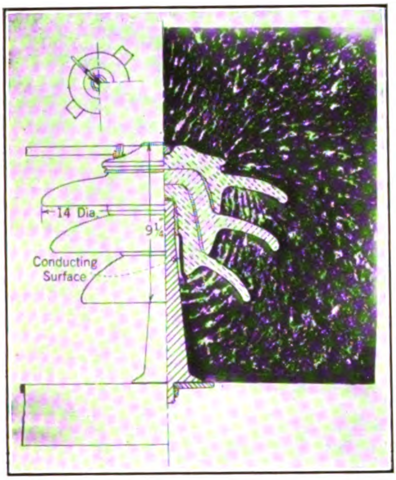

FIG. 17—INSULATOR G—DIELECTRIC FIELD ABOUT INSULATOR OF PROPOSED DESIGN

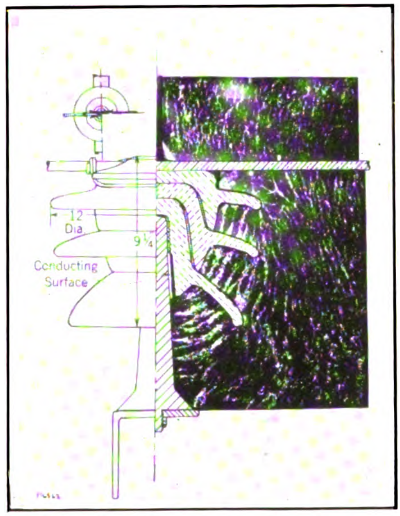

FIG. 18—INSULATOR F—DIELECTRIC FIELD ABOUT INSULATOR OF PROPOSED DESIGN UNDER CONDITIONS APPROXIMATING RAIN

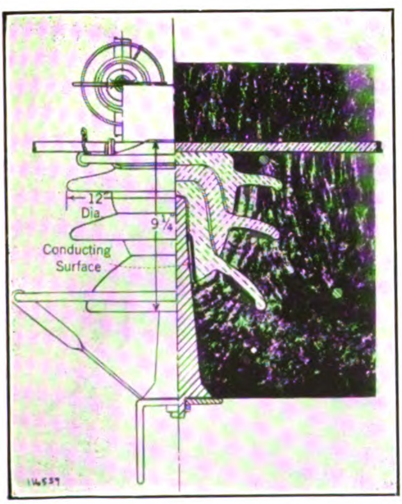

FIG. 19—INSULATOR F—DIELECTRIC FIELD ABOUT INSULATOR OF PROPOSED DESIGN INSTALLED WITH NICHOLSON ARCING RINGS

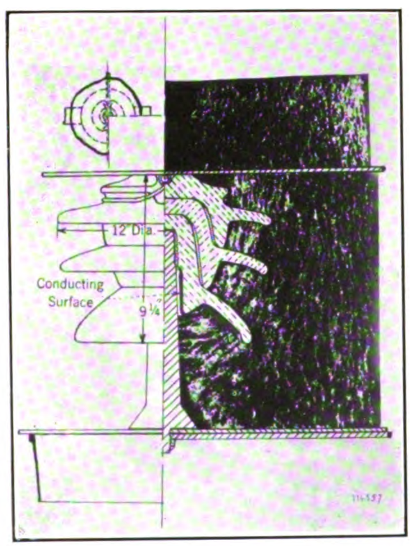

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FIG. 20—INSULATOR F—DIELECTRIC FIELD ABOUT INSULATOR HAVING STATIC SHIELDS AT TOP AND BASE

cement joints between shells. As the voltage applied to the insulator is increased, the area of the corona formation increases and static streamers gradually spread over the surface of the insulator sheds. The static streamers increase in length until the air insulation between them finally fails and flashover follows. Obviously, the path of the flashover will start along the path of these streamers and thus trouble may be caused by the intense heat of the power arc and rain sheds may be stripped from the insulator.

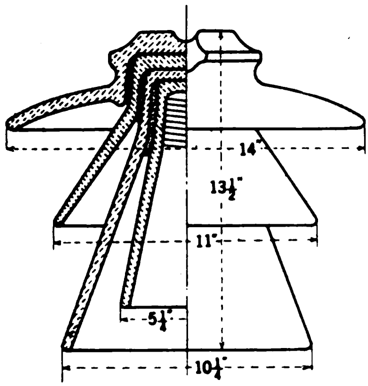

FIG. 21A—INSULATOR *I*

In the proposed type of design there are no static streamers from the edges of the cement section between shells up to flash-over voltage. The corona formation at the tie and line wires therefore, builds up until flashover occurs by breaking down an air path between the line and pin or cross arm. The proof of these statements may be seen in the following illustrations. The axes of the two units in each of the following figures giving comparative flashovers

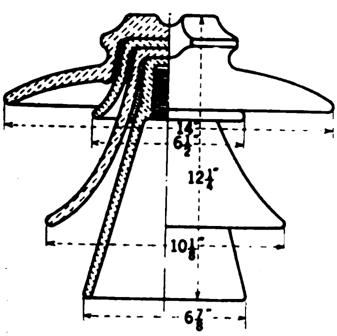

FIG. 21B—INSULATOR *K*

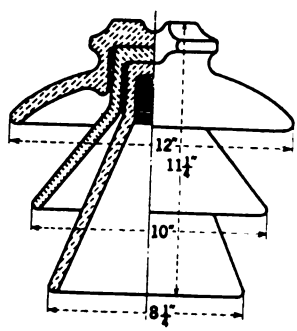

FIG. 21C—INSULATOR *H*

were at the same distance from the camera lens and hence the dimensions are directly comparable.

Figs. 22 and 23 show illustrations of dry and wet flashovers respectively, on insulators *G* and *H*. The design of insulator *H* is given in Fig. 21c.

Fig. 24 shows an illustration of wet flashover on insulators *J*

and *I*. The design of insulator *I* is given in Fig. 21A. Insulator *J* is of the proposed type similar to the unit given in Fig. 8.

Fig. 25 illustrates of one of the early types of high-voltage insulators and insulator *J* in parallel. The finer lines over the surface of the old type unit are preliminary static discharges. The final power arc passes from the left of the insulator head around in front of and finally to the pin at the back of the insulator.

Fig. 26 shows insulator *F* in parallel with the unit of early design shown in Fig. 25, and shows the corona formation and static discharge over the head and between the head and second shell of the old type unit. The camera exposure was ¾ of a minute at *F*-8.

The difference in the stress in the air around the insulators just below flashover voltage dry was very marked. Insulators *F*, *G* and *J* of the proposed type of design showed no appreciable corona except at line and tie wires until flashover occurred. Flashover occurred from tie wire or line wire to pin or cross arm, there being no tendency for the arc to start between the rain sheds. Considerable corona formation and static streamers could be dectected on insulators *E*, *H* and *I*. Static streamers began to spread out over the surfaces between shells of insulators *H* and *I* at 80 per cent of flashover voltage, and unless these units are mounted on rather low pins the power arc holds close to the insulator surfaces. Of course, the old type design of Figs. 25 and 26 has been entirely superseded but these two figures clearly indicate the entire neglect of a consideration of the dielectric field.

The difference of distribution of stress before wet flashover is even more noticable. In insulator *E*, *G*, *H* and *I* the unequal spacing of rain sheds and consequent unequal wet arcing distances, combined with a highly stressed air between the sheds below the cement sections produces preliminary discharges (marked *p*) between rain sheds. These preliminary discharges throw electrical impacts onto parts of the insulator and short circuit portions of the porcelain between the line and pin. Consequently, when a line surge occurs during a rain storm or when the unit is wet and dirty the factor of safety of these insulators in resisting puncture or flashover is actually no more, and sometimes is less, than it would be minus one of the shells.

Insulators *F*, *G* and *J* of the proposed design show no prelimi-

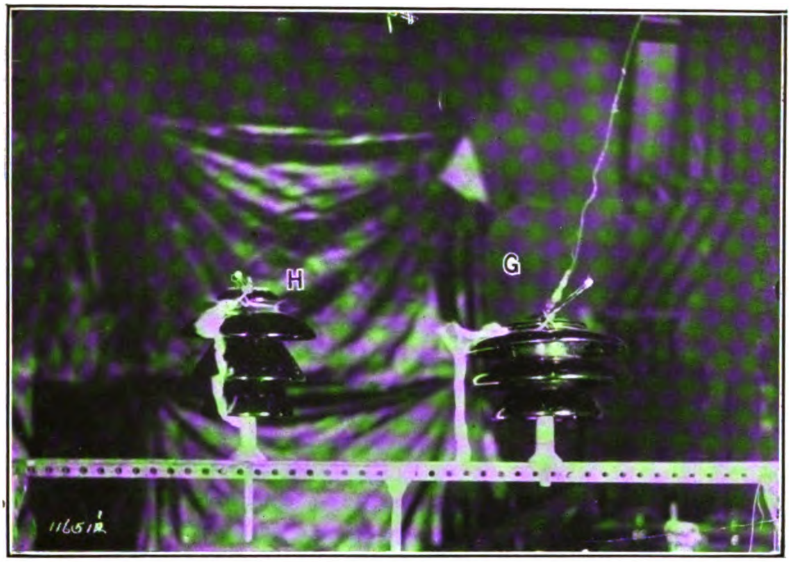

FIG. 22—60-CYCLE DRY FLASHOVER

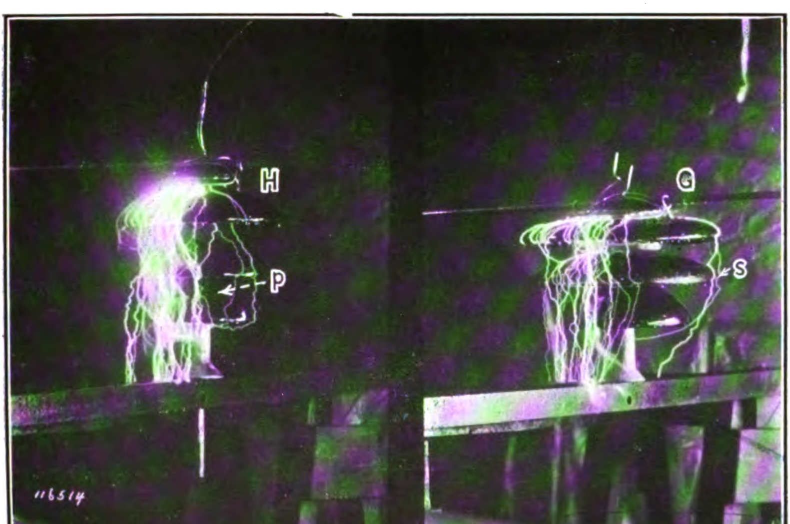

FIG. 23—60-CYCLE WET FLASHOVER

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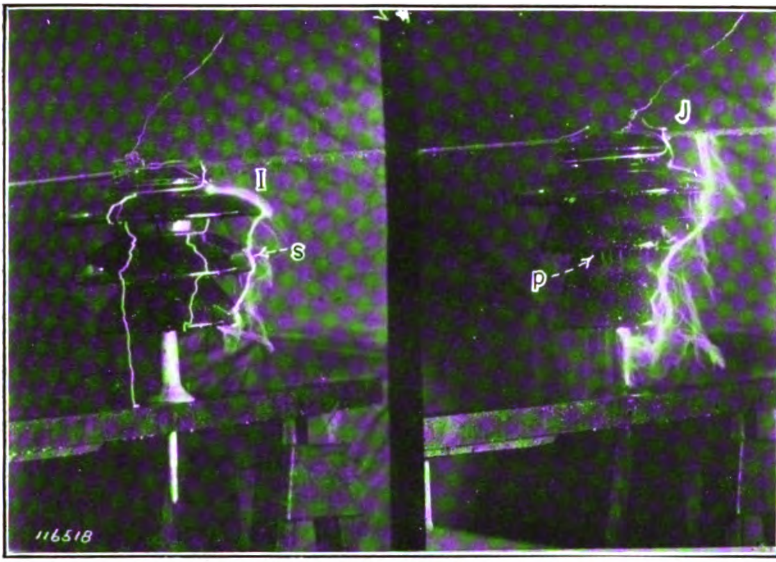

FIG. 24—60-CYCLE WET FLASHOVER

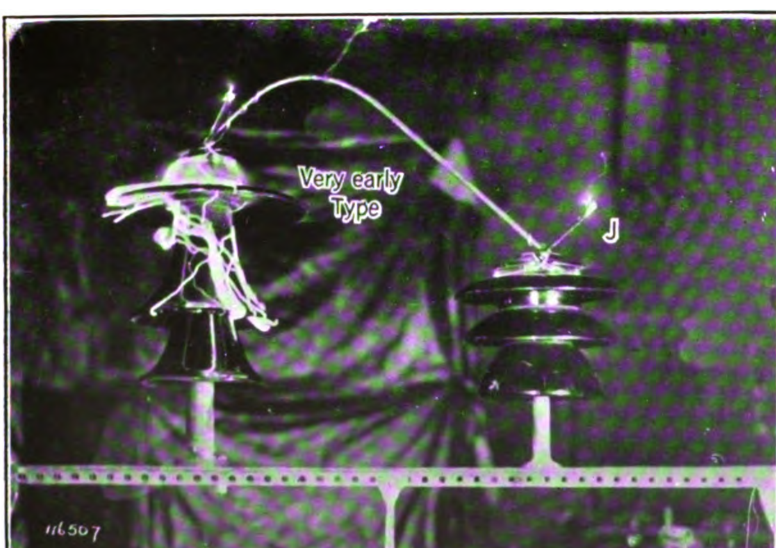

FIG. 25—60-CYCLE DRY FLASHOVER

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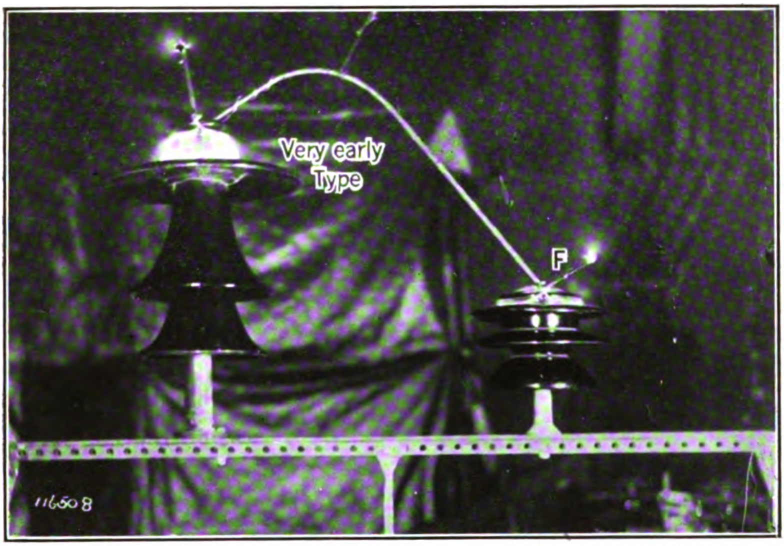

FIG. 26—60-CYCLE TEST—COMPARATIVE CORONA FORMATION

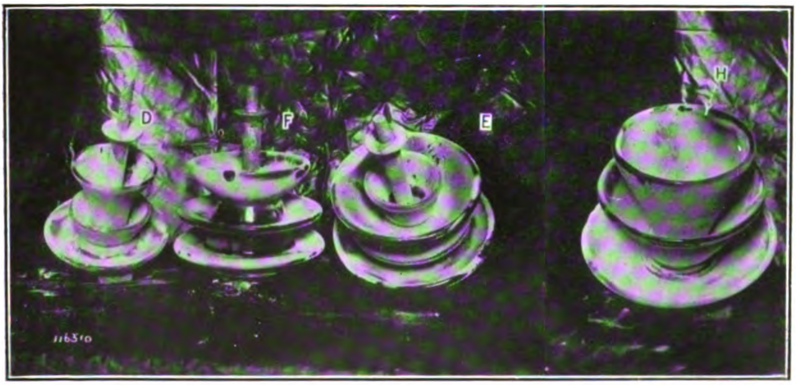

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FIG. 27—PLASTER PARIS DUST DEPOSITED WITH INSULATORS UNDER 60-CYCLE VOLTAGE

nary discharges except static from tie or line wires to pin or cross arm. Static discharges (marked *s*) are shown on each of these units. All of the leakage surface and thickness of porcelain between line and pin are, therefore, effective up to failure by flashover.

2—*Surface Leakage*. As previously stated, the leakage surface of many of the older designs gives a very uneven voltage distribution per shell. Table II gives the resistance per shell of various insulators tested during this investigation. The values were obtained by an integration of the surface, *i.e.*, surface resistance equals $S \frac{d\,s}{2\,\pi\,y}$ where $d\,s$ is an element of surface and y the radius of that element from the axis of the insulator.

It is obvious from this table that certain of the older designs especially those having a short second shell, long inner shells, etc., have a very unequal surface resistance per shell. If the insulator surface becomes dirty and wet so as to pass a leakage current of even a thousandth of an ampere the voltage distribution would depend upon this current and the capacity current could be neglected. The voltage gradient over the insulator surface thus often becomes sufficient to cause discharge between sheds and pin or cross arm or over the short sheds. An electrical impact is thereby applied to parts of the insulator and portions of the porcelain body between line and pin are short circuited. It is believed that the continued overstressing of parts has been the cause of many insulator failures in the past.

TABLE II

SURFACE RESISTANCE PER SHED IN PER CENT OF TOTAL RESISTANCE

Insulator	Number of shed			
	First	Second	Third	Fourth
A	28	30	42	. .
B	45	55	. .	. .
E	14	13	32	41
F	26	29	45	. .
G	26	31	43	. .
H	18	29	48	. .
I	12	16	32	40
K	15	11	30	44

The surface resistance of the proposed designs as typified by insulators *A* and *B* in Table II is gradually increased from the top

to center shells, the increase being considered as an advantage since the center sheds will usually become dirtiest.

A novel feature of the proposed design is illustrated in Fig. 27 showing insulators *D*, *E*, *F* and *H*. These units were set on a cross-arm line, and tie wire attached as in service, voltage applied and plaster of paris dust blown around them. The surfaces along the lines *a* of the proposed design (Fig. 8) are practically free of dust.

The reason for this is quite apparent. All the force acting in the dielectric field along this surface *a* is tangential and would tend to force the particles to the sheds above or below. The same action was noted when the units were subjected to atomized salt water. This feature would doubtless have some value in dust laden sections since the dust would tend to settle mostly on the lower shed and rain and wind would clean this to some extent.

It is necessary to clean the insulators in long portions of line in certain sections of country as the coast districts of California. It is very apparent that the proposed type of design may be cleaned much more readily and thoroughly than any of the older types.

3. *Porosity*. As denoted previously, the porosity of porcelain is a specific problem of the ceramic engineer rather than the designer. As clearly pointed out in a recent paper[3] by Prof. Ryan we apparently have no method of detecting the very slightly porous material which may cause trouble. Since porosity is a function of the body composition, manufacturing process and burning, even with the most careful production and testing, a small amount of this slightly porous material is not detected. The thicker portions of the porcelain in the cemented area of the proposed type of design should minimize the number of the pieces that will give trouble later in service.

4. *Mechanical Breakage*.

(a) From Handling: The increase of thickness of the rain sheds and addition of a drip edge will materially decrease the percentage loss from this cause.

(b) Mischievous Stone Throwing and Rifle Shooting: (1) The following photographs give comparative flashover voltages dry and wet on units having various rain sheds broken by throwing a small weight at the insulator. Figs. 22 and 23 show the dry and wet flashovers on insulators *G* and *H* respectively. Table III gives the flashover voltages of broken units in per

[3]loc. cit.

cent of flashover of the unit when unbroken. Reference to illustrations is made in the Table. Fig. 24 shows the wet flashover on units *J* and *I*. Table IV gives comparative flashovers of broken units, as in Table III.

TABLE III

Sheds broken....	Top		Second		Second and third	
Illustrated in Fig.		28	29	30	31	
Dry or wet......	dry	wet	dry	wet	dry	wet
Insulator *G*.....	85	80	100	100	68	74
Insulator *H*.....	79	77	82	97	54	70

TABLE IV

Sheds Broken.........	Top	Top and third	All sheds	
Photographs in Fig......................................32				
Dry or wet...........	dry	dry	dry	wet
Insulator *J*...........	87	78	59	30
Insulator *I*...........	85	70	34	15

As would be expected from a study of the dielectric field, diagrams the breaking of the second shed of the proposed type of design has practically no effect upon the flashover values of the insulator. In fact, as shown in the illustrations, the paths of the dry and wet flashovers did not follow over the broken shed. When sheds are broken, the corona formation and static streamers build out over the surface of the older type of design at a lower voltage than when the units are intact. The paths of flashover over these older types, therefore, follow the surface of the insulator. In the proposed type of design the absence of streamers from the porcelain surface causes the arc to keep clear of the insulator. A power arc will, therefore, be less liable to cause complete failure of a broken unit of the proposed design.

One of the most important features of the proposed design is that when the units are hit by stones, etc., the rain sheds will not crack or break beyond line *a* Fig. 8, due to the shape of the individual parts. The rain sheds of the older types of designs when hit are very likely to crack or break up into the cemented section. The first voltage surge or even normal line voltage will, therefore, often puncture the remaining shells. In fact, in the two series of tests photographed, both the older type of units

punctured during the dry arcover after sheds were broken. Static streamers shot over surface of insulator *H* in Fig. 31 and then puncture occurred. Insulator *I*, Fig. 32, flashed over and then punctured before the circuit breaker of the testing transformer operated.

(2) One each of units *H*, *I* and *K* and two of *J* were subjected to rifle shots. Twenty-two caliber long bullets were shot at the insulators from about 30 yards distance and in a line at 45 deg. to their axes. The following photographs show the comparative breakage and the ability of the broken units to thereafter withstand electrical test. The shooting was done by men disinterested in the design of the insulators and they were requested to do as much damage as possible.

Fig. 33 shows insulators *I* and *J* after 15 shots were fired at each. The top, second and third shells of *I* were broken, the second shell being cracked into the cemented section. The second shell of *J* was chipped in two places, the rest of the insulator being intact. Fig. 34 shows insulators *H*, *K* and *I* after 14 shots were fired at *H*, 12 at *K* and 28 at *I*. The second and center shells of *H* were cracked and the center of *K*. The sheds of *J* were chipped off in a few places but the shells were not cracked. These five units were than set with their axes at right angles to the line of fire. Not more than 5 or 10 shots were necessary to strip the main part of the remaining sheds from Insulators *H*, *K* and *I* while one unit of type *J* still retained a considerable portion of its sheds after approximately 100 shots had been fired at it. The sheds remaining on the two units *J* were then knocked off by a hammer, to illustrate to those present that the surface of the insulator that follows flow line *a* would not be cracked thereby.

Fig. 35 shows the first dry flashover test made on these units after the shooting. Units *H*, *K* and *I* punctured at voltage of 33, 43 and 56 kilovolts, respectively. Unit *J* flashed over at 105 kilovolts, the remaining porcelain body bounded by line *a* still being intact.

(*C*) *Insufficient Strength as a Support*: Two samples as per Fig. 36, were tested to determine the resistance to side pull. In each case load was applied at the wire groove which was one foot from the base of pin. The parts from which insulator *L* was formed were obtained by trimming off the rain sheds of individual shells of unit *J* before burning and the mechanical test should, therefore, be about the same as of unit *J*. The pin of

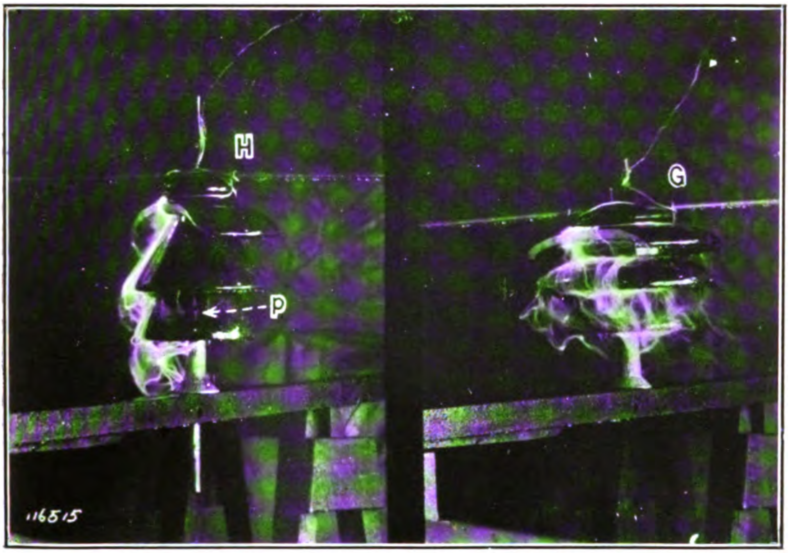

FIG. 28—TOP SHED BROKEN—60-CYCLE WET FLASHOVER

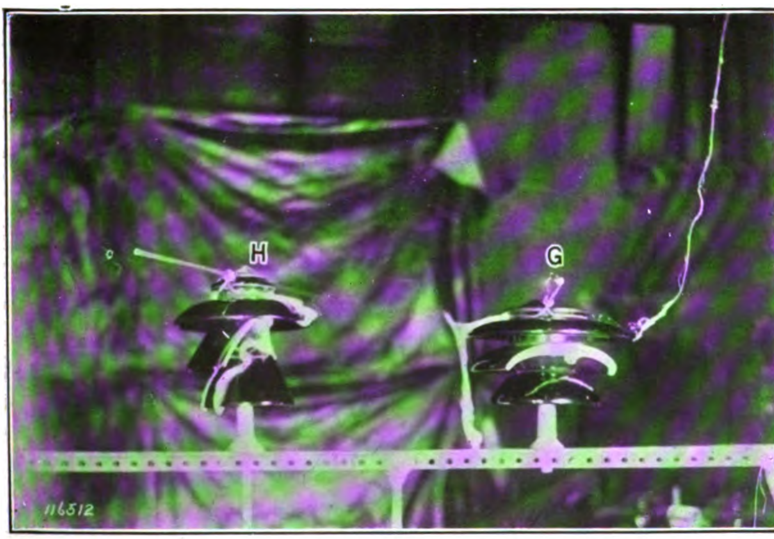

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FIG. 29—SECOND SHED BROKEN—60-CYCLE DRY FLASHOVER

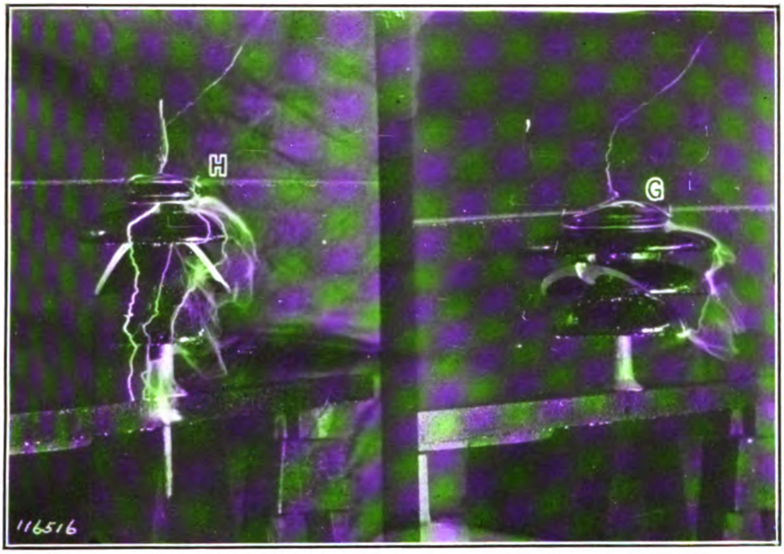

FIG. 30—SECOND SHED BROKEN—60-CYCLE WET FLASHOVER

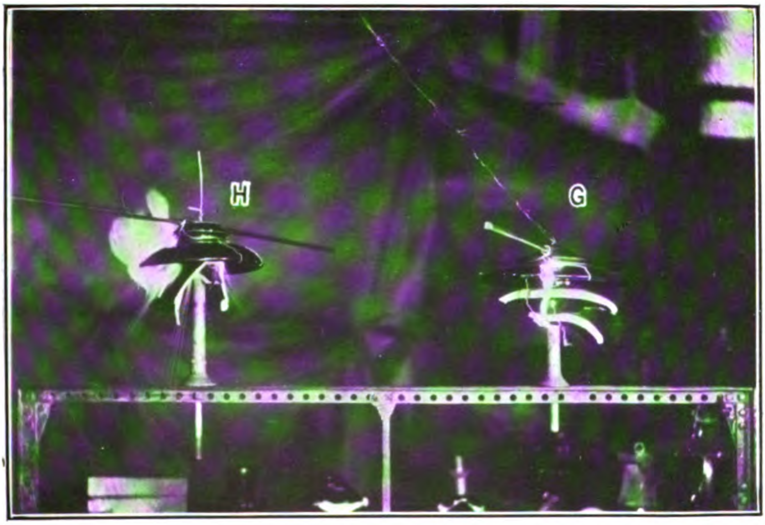

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FIG. 31—SECOND AND THIRD SHEDS BROKEN—60-CYCLE DRY FLASHOVER

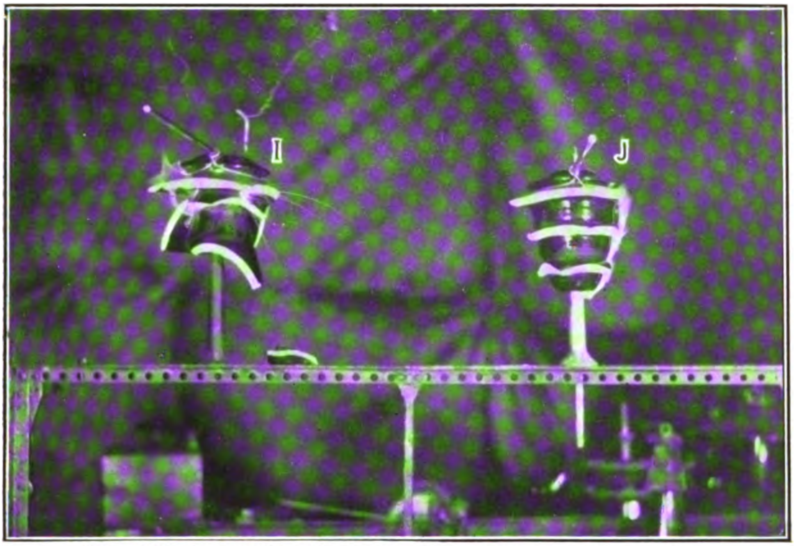
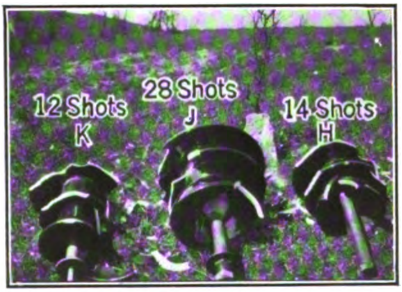


FIG. 32—ALL SHEDS BROKEN—60-CYCLE DRY FLASHOVER

FIG. 33—AFTER 15 SHOTS WERE FIRED AT EACH



[GILCHREST]

FIG. 34—AFTER NUMBER OF SHOTS AS INDICATED

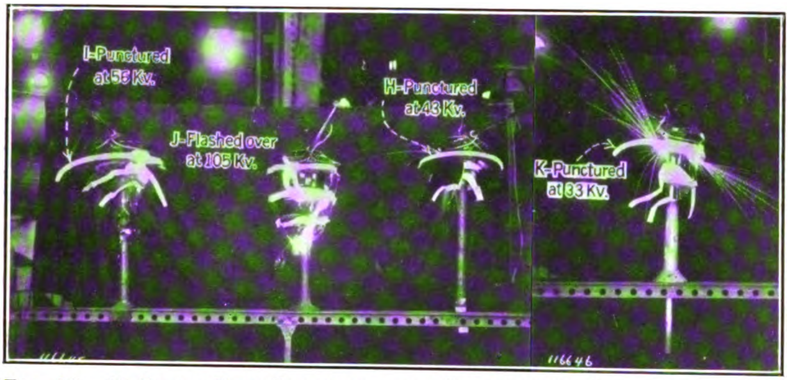


FIG. 35—60-CYCLE DRY FLASHOVERS ON INSULATORS *H*, *I* AND *J* AFTER BREAKAGE FROM RIFLE SHOTS

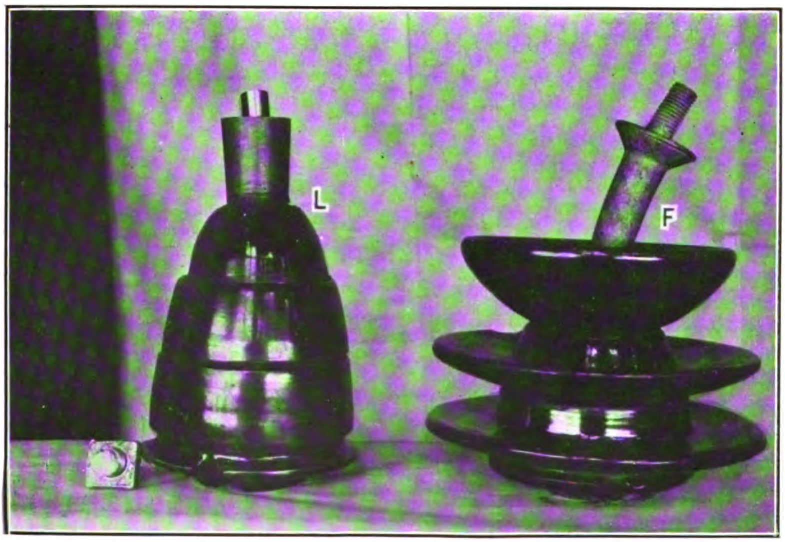


FIG. 36—RESISTANCE TO SIDE-PULL [GILCHREST]

unit L was cemented directly into the insulator. A separate pressed steel thimble was cemented into insulator F. The one-inch bolt of the pin cemented into insulator L failed at 4400 ft-lb., and 3100 ft-lb. bent the pin of insulator F as shown, the position of insulator being such that additional load could not be applied. Both units were electrically intact after these tests.

(d) *Brittle Material.* All units used in these comparative tests were made of the same porcelain body and hence the question of brittleness, which is a ceramic problem, does not enter.

5. *Lightning.* The impulse ratio of the proposed design is lower than that of most of the older types of design. The actual value has not been determined. This statement is based on tests of the proposed design in parallel with older types. The old types of design were set on a pin of such height above the cross arm as to cause the old type of unit to flash over when set up alone at a voltage slightly greater than that of the proposed type of design alone. When tested in parallel the static discharges over the porcelain surface of the older type would often cause the proposed type to flashover first.

Furthermore, the body of the porcelain bounded by the flow lines *a* should have an impulse ratio close to one. A very high impulse voltage might, therefore, puncture through the rain sheds of the insulator leaving this body of the unit intact. The thicker section of porcelain between line and pin will also materially increase the factor of safety of the unit.

(6) *Unequal Expanion of Metal, Cement and Porcelain.* The introduction of a resilient material between tops of shells should eliminate the tendency of certain older designs to split off. Greater radii of curvature at the tops of the insulator shells and a cement section sloped from the axis should tend to eliminate the trouble from any difference of coefficient of expansion of the porcelain and cement.

(7) *Internal Stresses in the Material.* Internal stresses set up in the insulator parts during manufacture should be very much decreased by the elimination of small radii in corners and sudden changes of cross section of the material.

Conclusions

Briefly stated, it is believed that the advantages of the proposed type over the older commercial types in resisting failure in service would be as follows:

1. When the insulator is dry, the corona and static forma-

tions are practically limited to the tie wire and line wire up to flashover voltage.

2. When the insulator is wet, no corona or static formation occurs up to flashover voltage. The flashover voltages for given overall dimensions are thereby increased.

3. The leakage resistance per shell is increased gradually from the head to the center shell. This takes into account the probability of the lower sheds becoming dirtier than the tops. The voltage distribution per shell is, therefore, equal when the insulator becomes dirty and wet and a heavy leakage current passes over the insulator.

4. Since the capacity per shell is about equal, the voltage distribution per shell will be equal when the insulator is clean and in dry air.

5. Since the distribution of voltage per shell depends upon the capacity current and leakage current, the distribution of voltage per shell in these designs should be approximately equal under all operating conditions.

6. The resistance of the insulator to side pull for a given weight and given electrical strength is relatively high. This is due to the feature of the design whereby the flow line *a* of the electrostatic field and the mechanical stress lines coincide.

7. The design of the individual shells is such that when they are tested before assembly the surface conforms to the electrostatic flow lines *a*. This allows testing of the individual parts to a higher percentage of service voltage than was possible in case of the individual shells of older designs.

8. Due to the shape of individual parts and of the assembled unit, the insulator sheds when hit by stones, rifle, balls, etc., do not break beyond surface *a*. The unit, therefore, offers a considerable percentage of its original resistance to flashover after the sheds are broken. The same feature tends to protect the insulator from complete failure during flashover in service.

9. Each characteristic of the insulator which would vitally affect durability in service has been treated uniformly throughout the line.

To be presented at the 34th Annual Convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 27, 1918.

AMERICA'S ENERGY SUPPLY

BY CHARLES P. STEINMETZ

ABSTRACT OF PAPER

The gist of the paper is to demonstrate that the economical utilization of the country's energy supply requires generating electric power wherever hydraulic or fuel energy is available, and *collecting the power electrically, just as we distribute it electrically.*

In the first section a short review of the country's energy supply in fuel and water power is given, and it is shown that the total potential hydraulic energy of the country is about equal to the total utilized fuel energy.

In the second section it is shown that the modern synchronous station is necessary for large hydraulic powers, but the solution of the problem of the economic development of the far more numerous smaller waterpowers is the adoption of the induction generator. However, the simplicity of the induction generator station results from the relegation of all the functions of excitation, regulation and control to the main synchronous station. The economic advantage of the induction generator station is, that its simplicity permits elimination of most of the hydraulic development by using, instead of one large synchronous station, a number of induction generator stations and collecting their power electrically.

The third section considers the characteristics of the induction generator and the induction-generator station, and its method of operation, and discusses the condition of "dropping out of step of the induction generator" and its avoidance.

In the appendix the corresponding problem is pointed out with reference to fuel power, showing that many millions of kilowatts of potential power are wasted by burning fuel and thereby degrading its energy, that could be recovered by interposing simple steam turbine induction generators between the boiler and the steam heating systems, and collecting their power electrically.* It is shown that the value of the recovered power would be an appreciable part of that of the fuel, and that organized and controlled by the central stations, this fuel power collection would improve the station load factor, give the advantages of the isolated plant without its disadvantages, and produce a saving of many millions of tons of coal.

I. The Available Sources of Energy

A. COAL

THE only two sources of energy, which are so plentiful as to come into consideration in supplying our modern industrial civilization, are coal, including oil, natural gas, etc., and water power.

*Manuscript of this paper was received April 9, 1918.

While it would be difficult to estimate the coal consumption directly, it is given fairly closely by the coal production, at least during the last decades, where wood as fuel had become negligible and export and import, besides more or less balancing each other, were small compared with the production. Coal has been mined since 1822, and in Fig. 1 is recorded the coal production of the United States, from the governmental reports. The annual production is marked by circles, the decennial average marked by crosses for every five years. Table I gives the decennial averages, in millions of tons per year.

TABLE I

AVERAGE COAL PRODUCTION OF THE UNITED STATES

(decennial average)

Year	Million tons per year	Per cent increase per year
1825	0.11	....
30	0.32	22.4
35	0.83	19.7
40	1.92	17.0
45	4.00	14.5
50	7.46	10.45
55	10.8	8.35
60	16.6	8.72
65	25.9	9.22
70	40.2	8.58
75	56.8	7.42
80	82.2	7.95
85	122	6.80
90	160	5.40
95	206	5.75
1900	281	6.96
05	404	6.60
10	532	....

In Fig. 1 the logarithms of the coal production in tons are used as ordinates. With this scale, a straight line means a constant proportional increase, that is, the same percentage increase per year, and in the third column of Table I are given the average percentage increase of coal production per year.

This Fig. 1 is extremely interesting by showing the great irregularity of production from year to year, and at the same time a very great regularity over a long period of time. Since 1870 the average production may be represented by a straight line, the values lying irregularly above and below the line, which

represents an annual increase of 6.35 per cent and thus represents the average coal production[1] C by the equation

$$C = 45.3 \times 10^{0.0267\,(y-1870)} \text{ million tons}$$

or

$$\log C = 0.0267\,(y-1870) + 7.656$$

where y = year.

Before this time, from 1846 to 1884, the coal production could be represented by

$$C = 7.26 \times 10^{.0365\,(y-1850)} \text{ million tons}$$

or

$$\log C = 0.0365\,(y-1850) + 6.861$$

representing an average annual increase of 8.78 per cent.

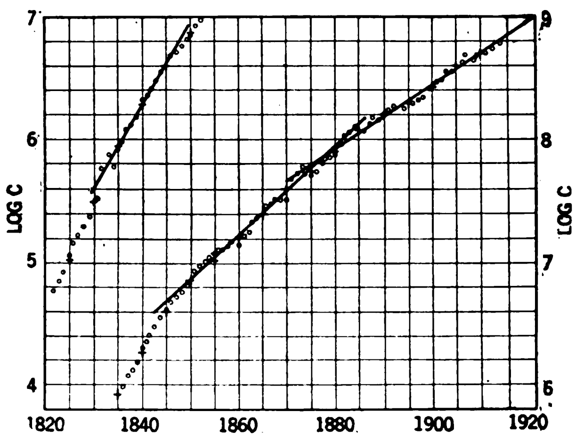


FIG. 1—COAL PRODUCTION OF THE UNITED STATES

It is startling to note how inappreciable, on the rising curve of coal production, is the effect of the most catastrophic political and industrial convulsions, such as the Civil War and the Industrial panic of the early 90's; they are indistinguishable from the constantly recurring annual fluctuations. It means, that the curve is the result of economic laws, which are laws of nature.

Extrapolating from the curve of Fig. 1, which is permissible, due to its regularity, gives 867 million tons as this year's coal consumption. As it is difficult to get a conception of such enormous amounts, I may be allowed to illustrate it. One of the great wonders of the world is the Chinese Wall, running

1. Soft coal and anthracite, and including oil reduced to coal by its fuel value.

across the country for hundreds of miles, by means of which China unsuccessfully tried to protect its nothern frontier against invasion. Using the coal produced in one year as building material, we could with it build a wall like the Chinese Wall, all around the United States, following the Canadian and Mexican frontier, the Atlantic, Gulf and Pacific Coast, and with the chemical energy contained in the next year's coal production, we could lift this entire wall up into space, 200 miles high. Or, with the coal produced in one year used as building material, we could build 400 pyramids, larger than the largest pyramid of Egypt.

It is interesting to note that 100 thousand tons of coal were produced in the United States in 1825; one million tons in 1836; 10 million tons in 1852 and 100 million tons in 1882. The production will reach about 1000 million tons in 1920, and, if it continues to increase at the same rate, it would reach 10,000 million tons in 1958.

Estimating the chemical energy of the average coal as a little above 7000 cal., *the chemical energy of one ton of coal equals approximately the electrical energy of one kilowatt year* (24 *hour service*). That is, one ton of coal is approximately equal in potential energy to one kilowatt-year.

Thus the annual consumption of 867 millions of tons of coal represents, in energy, 867 million kilowatt-years.

However, as the average efficiency of conversion of the chemical energy of fuel into electrical energy is probably about 10 per cent, the coal production, converted into electrical energy, would give about 87 million kilowatts.

Assuming however, that only one half of the coal is used for power, at 10 per cent efficiency, the other half as fuel, for metallurgical work etc., at efficiencies varying from 10 per cent to 80 per cent, with an average efficiency of 40 per cent, then we get 217 million kilowatts (24 hour service) as the total utilized energy of our present annual coal production of 867 million tons.

B. The Potential Water Powers of the United States

Without considering the present limitation in the development of water powers, which permits the use of only the largest and most concentrated powers, we may try to get a conception of the total amount of hydraulic energy which exists in our country, irrespective of whether means have yet been developed

or ever will be developed for its complete utilization. We therefore proceed to estimate the energy of the total rain fall.

Superimposing the map of rain fall in the United States, upon the map of elevation, we divide the entire territory into sections by rain fall and elevation. This is done in Table II, for the part of our continent between 30 and 50 degrees northern latitude.

TABLE II

TOTAL POTENTIAL WATER POWER OF UNITED STATES

In. rain fall	Ft. elevation	Area $m^2 10^{12} \times$	Avg. elevation m.	Avg. rainfall cm.	Kg-m. per m^2; $10^3 \times$	Kg-m total $10^{15} \times$
>10	>5000	0.54	2100	12.5	263	142
	1000–5000	0.29	900		112	32.5
10–20	>5000	1.18	2100	37.5	787	930
	1000–5000	1.96	900		338	660
20–30	1000–5000	0.32	900	62.5	563	183
	100–1000	0.97	150		94	91
30–40	1000–5000	0.35	900	87.5	786	275
	100–1000	1.40	150		131	184
40–60	1000–5000	0.27	900	125	1130	305
	100–1000	1.03	150		188	194
						$\Sigma = 2996$
						3000

As obviously only the general magnitude of the energy value is of interest, I have made only few sub-divisions: five of rain fall and four of elevation, as recorded in columns 1 and 2 of Table II[2]. The third column gives the area of each section, in millions of square kilometers, the fourth column the estimated average elevation, in meters, and the fifth column the average rain fall, in centimeters. The sixth column gives the energy, in kilogram-meters per square meter of area, and the last column the total energy of the section, in kilogram-meters, which would be represented by the rain fall, if the total hydraulic energy of every drop of rain were counted, from the elevation where it fell, down to sea level.

As seen from Table II, the total rain fall of the North American Continent between 30 deg. and 50 deg. latitude represents 3000×10^{15} kg-m. This equals 950 million kilowatt years (24 hour service). That is, the total potential water power of the United States, or the hydraulic energy of the total

1. The lowest elevation, < 100 ft., is not included, as having little potential energy.

rain fall, from the elevation where it fell, down to sea level, gives about 1000 million kilowatts.

However, this is not available, as it would leave no water for agriculture; and even if the entire country were one hydraulic development, there would be losses by seepage and evaporation.

An approximate estimate of the maximum potential power of the rain fall, after a minimum allowance for agriculture and for losses is made in Table III, allowing 12.5 cm. rain fall for wastage, and 37.5 and 25 cm. respectively for agriculture where such is feasible.

TABLE III

AVAILABLE POTENTIAL WATER POWER OF THE UNITED STATES

Avg. rainfall cm.	Avg. elevation m.	Area m^2 $10^{12}\times$	Wastage cm.	Agriculture, cm.	Available rainfall cm.	Kg. m. per m^2 $10^3\times$	Kg-m. total $10^{15}\times$
12.5	2100	0.54	12.5	....	....	....	....
....	900	0.29	12.5	....	....	....	....
37.5	2100	0.39	12.5	25	....	....	....
....	2100	0.79	12.5	....	25	525	415
....	900	0.98	12.5	25	....	....	....
....	900	0.98	12.5	....	25	225	220
62.5	900	0.21	12.5	37.5	12.5	112	23
....	900	0.11	12.5	....	50	450	50
....	150	0.97	12.5	37.5	12.5	19	18
87.5	900	0.35	12.5	37.5	37.5	337	118
....	150	1.40	12.5	37.5	37.5	56	78
125	900	0.27	12.5	27.5	75	674	182
....	150	1.03	12.5	37.5	75	112	116
							$\Sigma = 1220$

This gives about 1200 $\times$ 10^{15} kg-m. as the total available potential energy, which is equal to 380 million kilowatts (24 hour service). Assuming now an efficiency of 60 per cent from the stream to the distribution center, gives 230 million kilowatts (24 hour service) as the maximum possible hydroelectric power, which could be produced, if every river, stream, brook or little creek throughout its entire length, from the Spring to the ocean, and during all seasons, including all the waters of the freshets, were used and could be used. It would mean that there would be no more running water in the country, but stagnant pools connected by pipe lines to turbines exhausting into the next lower pool. Obviously, we could never hope to develop more than a part of this power.

C. Discussion

It is interesting to note that the maximum possible hydraulic energy of 230 million kilowatts, is little more than the total energy which we now produce from coal, and is about equal to the present total energy consumption of the country, including all forms of energy.

This was rather startling to me. It means that the hope that when coal once begins to fail we may use the water powers of the country as the source of energy, is and must remain a dream, because if all the potential water powers of the country were now developed, and every rain drop used, it would not supply our present energy demand.

Thus hydraulic energy may and should supplement that of coal, but can never entirely replace it as a source of energy. This probably is the strongest argument for efforts to increase the efficiency of our methods of using coal.

A source of energy which is practically unlimited, if it could only be used, is solar radiation. The solar radiation at the earth's surface is estimated at 1.4 cal. per cm.^{2} per min. Assuming 50 per cent cloudiness, this would give an average throughout the year (24 hours per day), of about 0.14 cal per cm.^{2} horizontal surface per min., and on the total area considered in the preceding table, of 8.3 million square kilometers of North America between 30 and 50 latitude, a total of approximately 800,000 million kilowatts (24 hour service), or a thousand times as much as the total chemical energy of our coal consumption; 800 times as much as the potential energy of the total rainfall.

Considering that the potential energy of the rainfall from surface level to sea level, is a small part of the potential energy spent by solar radiation in raising the rain to the clouds, and that the latter is a small part of the total solar radiation, this is reasonable.

Considering only the 2.7 million square kilometers of Table III, which are assumed as unsuited for agriculture, and assuming that in some future time, and by inventions not yet made, half of the solar radiation could be collected, this would give an energy production of 130,000 million kilowatts.

Thus, even if only one-tenth of this could be realized, or 13,000 million kilowatts, it would be many times larger than all the potential energy of coal and water. Here then would be the great source of energy for the future.

II. Hydroelectric Station

A. The Modern Synchronous Generator Station

In developing the country's water powers, up to the present time only those of greatest energy concentration have been considered; that is, those where a large volume and a considerable head of water was available within a short distance.

This led to the present type of hydroelectric generating station, as best solving the problem. The equipment of such a station comprises the following apparatus:

Three-phase synchronous direct-connected generators.

Hydraulic turbines of the highest possible efficiency.

Hydraulic turbine speed governing mechanism.

An exciter plant comprising either exciters directly connected to the generators, or several separate exciter machines, connected to separate turbines.

Exciter bus bars.

Voltmeter, and ammeters in exciters and in alternator field circuits.

Field rheostats of the alternators.

Low-tension busbars, either in duplicate, or with transfer or synchronizing bus.

Circuit breakers between generators and busbars, usually non-automatic.

Circuit breakers between transformers and busbars, usually automatic, with time limit.

Voltmeters and potential transformers at the generators.

Synchronoscopes or other synchronizing devices.

Ammeters and current transformers at the generators.

Voltmeter and potential transformer at the busbars.

Ammeters and current transformers at the step-up transformers.

Totaling ammeter for the station output.

Integrating wattmeter.

Relays, interlocking devices etc., etc.

Step-up transformers.

High-tension busbars, possibly in duplicate.

High-tension circuit breakers between transformers and high-tension busbars.

High-tension circuit breakers between high-tension busbars and lines.

Lightning arresters in the transmission lines, with inductances etc.

Ground detectors, arcing-ground or short-circuit suppressors, voltage indicators etc.

Automatic recording devices (multi-recorder), rarely used though very desirable.

Due to the vast amount of energy controlled by modern stations, the auxiliary and controlling devices in these stations have become so numerous as to make the station a very complex structure, requiring high operating skill and involving high cost of installation. At the same time, not only are all these devices necessary for the safe operation of the station, but we must expect that with the further increase of capacity of our electric systems, additional devices will become necessary for safe and reliable operation. One such device I have already mentioned—automatic recording apparatus, such as the multi-recorder.

With this type of station, it is obviously impossible, in most cases, to develop water powers of small and moderate size. A generating station of a thousand horse power will rarely, and one of a hundred horse power will hardly ever be economical.

On the other hand, a hundred horse power motor installation is a good economical proposition, and the average size of all the motor installations is probably materially below one hundred horse power.

Looking over Tables II and III, especially the latter, in the preceding section, it is startling to see how large a part of the potential water power of the country is represented by comparatively small areas of high elevation, in spite of the relatively low rainfall of these areas. As most of these areas are at considerable distance from the ocean, most of the streams are small in volume. That is, it is the many thousands of small mountain streams and creeks, of relatively small volume of flow, but high gradients, affording fair heads, which apparently make up the bulk of the country's potential water power.

Only a small part of the country's hydraulic energy is found so concentrated locally as to make its development economically feasible with the present type of generating station.

Therefore, some different, and very much simpler type of generating station must be evolved, before we can attempt to develop economically these many thousands of small hydraulic powers, to collect the power of the mountain streams and creeks.

B. Simplification of Hydroelectric Station

In the following in discussing the simplification of the hydroelectric station to adapt it to the utilization of smaller powers, we limit ourselves to the case where the smaller hydraulic stations feed into a system containing some large hydraulic or steam turbine stations, to which the control of the system may be relegated.

1. We may eliminate the low tension bus bars, with generator circuit breakers and transformer low-tension circuit breakers and connect each generator directly to its corresponding transformer making one unit of generator and transformer, and do the switching on high-tension busbars, and locating high-tension busbars and circuit breakers outdoors. While it is dangerous to transformers to switch on the high-tension side, due to the possibility of cumulative oscillations, this danger is reduced by the permanent connection of the transformer with the generator circuit, and is less with the smaller units used in small power stations, and thus permissible in this case.

However, the simplification resulted therefrom is not so great, as ammeters, voltmeter and synchronizing devices with their transformers are still retained on the low-tension circuits.

2. As it is not economical to operate at partial load, proper operation of a hydraulic station on a general system is, to operate as many units fully loaded as there is water available, and increase or reduce the number of units (of turbine, generator and transformer, permanently joined together), with the changing amount of available water, thus using all the available energy of the water power.

In this case, the turbine governors, with their more or less complex hydraulic machinery, may be omitted. If then the generators are suddenly shut down by a short circuit which opens the circuit breakers, the turbines will race and run up to their free running speed, until the gates are shut by hand. However, generators, and turbines must stand this, as even with the use of governors, the turbines may momentarily run up to their free speed in case of a sudden opening of the load, before the governors can cut off the water. Where this is not desirable some simple excess speed cut-off may be used.

3. When dropping the governing of the turbines, and running continuously at full load, the question may be raised whether generator ammeters are necessary, as the load is constant, and is all the power the water can give, and it might appear, that am-

meters with their current transformers, etc. could be omitted. However, with synchronous generators, the current depends not only on the load, but also on the power factor of the load and with excessively low power factor due to wrong excitation, the generators may be overheated by excess current, while the power load is well within their capacity. Thus ammeters are necessary with synchronous generators. As soon, however, as we drop the use of synchronous generators, and adopt induction generators, the ammeters with their current transformers may be omitted, since the current and its power factor is definitely fixed by the load. At the same time, synchronizing devices become unnecessary, together with potential transformers, generator voltmeters, etc. A station voltmeter may be retained for general information, but it not necessary either, as the voltage and frequency of the induction-generator station are fixed by the controlling synchronous main station of the system.

4. With the adoption of the induction generator, the entire exciter plant is eliminated, as the induction generator is excited by lagging currents received from synchronous machines, transmission lines and cables existing in the system. This avoids the use of exciter machines, exciter busses, ammeters, voltmeters, alternator field rheostats, etc., in short, most of the auxiliaries of the present synchronous station become unnecessary.

The solution of the problem of the economic development of smaller water powers is the adoption of the induction generator.

Stripped of all unnecessary equipment, the smaller hydroelectric station thus would comprise:

Hydraulic turbines of simplest form, continuously operating at full load, without governors.

Low-voltage induction generators direct connected to the turbines.

Step-up transformers direct connected to the induction generators.

High-tension circuit breakers connecting the step-up transformers to the transmission line. In smaller stations, even these may be dispensed with and replaced by disconnecting switches and fuses.

Lightning arresters on the transmission line where the climatic or topographical location makes such necessary.

A station voltmeter, a totalling ammeter or integrating wattmeter and a frequency indicator may be added for the informa-

tion of the station attendant, but are not necessary, as voltage, current, output and frequency are not controlled from the induction generator station, but from the main station, or determined by the available water supply.

It is interesting to compare this induction generator station lay-out with that of the modern synchronous station given above. However, it must not be forgotten that *the simplicity of the induction generator station results from the relegation of all the functions of excitation, regulation and control, to the main synchronous stations* of the system, and the induction generator stations thus are feasible only as adjuncts to at least one large synchronous station, hydraulic or steam turbine, in the system, but can never replace the present synchronous generator stations in their present field of application.

C. Automatic Generating Stations

With the enormous simplification resulting from the use of the induction generator, it appears entirely feasible to make smaller hydroelectric generating stations entirely automatic, operating without attendance beyond occasional—weekly or daily—inspection.

Such an automatic generating station would comprise a turbine with low-voltage induction generator, housed under a shed, and a step-up transformer, outdoors, connecting into the transmission line with time fuses and disconnecting switches.

It is true that in the big synchronous generating stations of thousands of kilowatts, the cost of the auxiliaries, as exciter plant, regulating and controlling devices, etc., is only a small part of the total station cost, and little would therefore be saved by the use of induction generators. No induction generators would, however, be used for such stations. But the cost of auxiliaries and controlling devices, and the cost of the required skilled attendance, decreases far less with decreasing station size than that of the generators—whether synchronous or induction —or in other words, with decreasing size of the station, *per kilowatt output*, the cost of auxiliaries and controlling devices and of attendance increases at a far greater rate than that of the generators, and very soon makes the synchronous station of the present type uneconomical.

It is also true that in the big modern hydraulic power systems, the cost of the generating station usually is a small part of the cost of the hydraulic development. Therefore any saving in

the cost of the generating station would be of little influence in determining, whether the hydraulic development would be economical. With decreasing size of the water power the cost of the hydraulic development *per kilowatt output* usually increases so rapidly as very soon to make the development of the water power uneconomical, no matter how simple and cheap the station is.

However, the value of the induction generator is not so much in the reduction of the cost of the generating station, as in the reduction of the cost of the hydraulic development, by making it possible to apply to the electric generator the same principle, which has made the electric motor economically so successful: *Collect the power electrically, just as we distribute it electrically.*

We do not, as in the days of the steam engine, convert the electric power into mechanical power at one place, by one big motor, and distribute the power mechanically, by belts and shafts, but we distribute the power electrically, by wires, and convert the electric power to mechanical power, wherever mechanical power is needed, by individual motors throughout mill and factory.

In the same way we must convert the hydraulic, that is, mechanical power into electrical power by individual generators located along the streams or water courses within the territory, wherever power is available, and then collect this power electrically, by medium-voltage collecting lines and high-voltage transmission lines, and so eliminate most of the cost of the hydraulic development, to solve the problem of the economical utilization of the country's water powers. If we attempt to collect the power mechanically, that is, by a hydraulic development gathering the waters of all the streams and creeks of a territory together into one big station, and there convert it into electric power, the cost of the hydraulic development makes it economically hopeless except under unusually favorable conditions, where a very large amount of power is available within a limited territory, or where nature has done the work for us in gathering considerable power at a waterfall, etc.

It is the old problem, and the old solution: If you want to *do it economically, do it electrically.*

Naturally then, we would use induction generators in these small individual stations just as we use induction motors in individual motor installations; but where large power is available, there is the field of the synchronous generator, and the induction generator is undesirable, just as the synchronous motor

is preferable where large power is required—unless the synchronous motor is excluded by conditions of starting torque, etc.

At first, and for some time to come, we would not consider going to anywhere near as small sizes of induction generators, as we do in induction motors. However, there are undoubtedly many millions of kilowatts available in water powers throughout the country, which can be collected by induction-generator stations from 50 h.p. upwards, and that at fair heads, requiring no abnormal machine design (no very slow speed).

Consider an instance—a New England mill river with a descent, in its upper course, of about 1100 ft. (335 m.) within five miles (eight km.), of varying gradient. At three places, where the gradient is steepest, by a few hundred feet of cast iron pipe and a small dam of 20 to 30 ft. (6 to 9 m.) length and a few feet height—just enough to cover the pipe intake—an average head of 150 ft. (45 m.) can be secured, giving an average of 75 h.p. each, or a total of 225 h.p. or 170 kw. This would use somewhat less than half the total potential power. The development of the other half, requiring greater length of pipe line, or involving lower heads, would be left to meet future demands for additional power.

The installation of an electric system of 170 kw. would hardly be worth while, but there are numerous other creeks throughout the territory from which to collect power, and within a few miles passes a high potential transmission line, coming from a big synchronous station, into which the power collecting lines coming from the induction generator stations would be tied and from which they would be controlled.

Thus, the large modern synchronous station has its field, and is about as perfect as we know how to build for large concentrated powers; but beyond this, there is a vast field, and therefore *an economic necessity of the development of a different type of hydraulic generating station to collect the scattered water powers* of the country; and that is the *induction generator station*, to which I wish to draw the attention.

I must caution, however, not to mistake small power and low head power. There are on the lower courses of our streams some hydraulic powers, which are relatively small due to their low heads, and which can not be economically developed by the synchronous generator, due to the low head and correspondingly low speed. The designing characteristics of the induction generator, with regard to low-speed machines, are no better—if

anything rather worse—than those of the synchronous generator, and the problem of the economical utilization of the low-head water power still requires solution. It is not solved by the induction generator; the latter's characteristic is simplicity of the station, giving the possibility of numerous small automatic generating stations.

III. Induction Generator Station

A. Characteristics of Induction Generator

An induction motor at no load runs at, or rather very close to synchronism. If it is driven above synchronism by mechanical power, current and power again increase, but the electric power is outflowing, and the induction machine consumes mechanical power, and generates electrical power, as an induction generator.

The maximum electrical power, which an induction machine can generate as an induction generator is materially larger than the maximum mechanical power, which the same machine, at the same terminal voltage, can produce as an induction motor.

Resolving the current of the induction machine into an energy component and a wattless or reactive component, the energy current is inflowing, representing consumption of electric power (which is converted to mechanical power) below synchronism. It becomes zero near synchronism, and above synchronism the energy current is in the reverse direction, or outflowing, supplying electric power to the system (which is produced from the mechanical power input into the machine), and the induction machine then is a generator.

The wattless or reactive component is a minimum at synchronism, and increases with the slip from synchronism, and is in the same direction, whether the slip is below synchronism, as a motor, or above synchronism, as a generator. That is, the induction machine always consumes a lagging current (representing the exciting current and the reactance voltages), or, what amounts to the same, produces a leading current. The latter way of putting it is frequently used with induction generators, by saying that the current produced by the induction generator is leading, while the current consumed by the induction motor is lagging. Instead of saying however, that the reactive component of the current generated by the induction generator is leading, we may say, and this makes it often more intelligible, that the induction generator generates an energy current and consumes a lagging reactive current, while the induction motor consumes an energy current and consumes a reactive lagging current.

As with the increasing voltages and increasing extent of our transmission systems the leading currents taken by transmission lines and underground cables are becoming increasingly larger, the induction generator appears specially advantageous, as tending to offset the effect of line capacity. We may thus say that the induction generator (and induction motor) consumes a lagging reactive current, which is supplied by the synchronous generators, synchronous motors, converters and other synchronous apparatus in the system, and by the capacity of lines and cables. Or we may say that the lagging current consumed by the induction generator neutralizes the leading current consumed by the capacity of lines and cables. Or we may say that the leading current produced by the induction

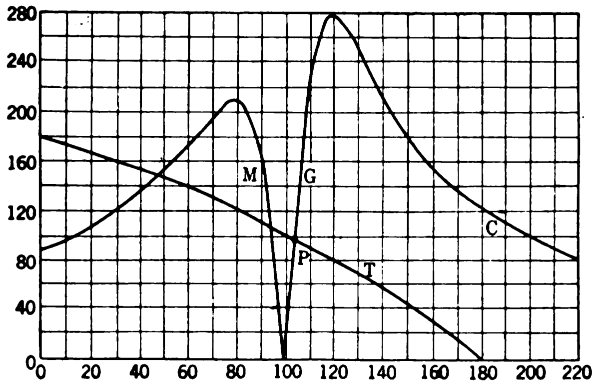


FIG. 2—SMALL HYDROELECTRIC INDUCTION GENERATOR PLANT CONSTANT TERMINAL VOLTAGE

generator supplies the capacity of lines and cables: these are merely three different ways of expressing the same facts.

In Fig. 2 are shown the torque curves, at constant terminal voltage, of a typical moderate size induction machine. *M* is the torque produced as an induction motor below synchronism, and *G* the torque consumed as an induction generator above synchronism, synchronism being chosen as 100 per cent. *T* is an assumed torque curve of a hydraulic turbine.

As seen, the point *P* where *G* and *T* intersect, is 4 per cent above synchronism, and this induction generator thus operates on full load at 4 per cent slip above synchronism or no-load. Assuming now, that the power goes off, by the circuit breakers opening. The turbine then speeds up to 80 per cent above

synchronism, where the curve T becomes zero. If at this free running turbine speed the circuit is closed and voltage put on the induction generator, the high torque consumed by the induction generator causes the turbine to slow down, and as at all speeds above 104, the torque consumed by the induction generator is very much higher than that given by the turbine, the machine slows down rapidly, to the speed where the induction generator torque has fallen to equality with the turbine torque, at speed 104, and stable condition is restored.

Inversely, if the flow of water should cease, the induction machine slows down to a little below synchronism, and there continues to revolve as induction motor.

In starting, the circuit may be closed before admitting the water, and the turbine started by the induction machine as a motor, on the torque curve M, running up to speed 100, and then, by admitting the water, the machine is speeded up 4 per cent more and thereby made to take the load as generator. Or the turbine may be started by opening the gates, running up to speed 180, and then, by closing the circuit, the induction machine in taking the power slows the speed down to normal.

With larger machines, the most satisfactory way of starting, as involving the least disturbance, probably would be, first to open the gates partly while the turbine speeds up, and when it has reached a speed in the neighborhood of synchronism, say between 95 and 105, the circuit is closed and the water gates opened fully.

B. Instability Conditions of Induction Generator

In Fig. 2, the torque consumed by the induction machine, at all turbine speeds above full load P, is much higher than the torque of the turbine. However, the induction generator torque curve has a concave range, marked by C, and if the induction generator should be such as to bring the generator torque curve at C below the turbine torque curve T, the speed, when once increased beyond the range C, would not spontaneously drop back to normal. While in Fig. 2, C is much higher than T, Fig. C represents the theoretical, but not real case of constant terminal voltage at the induction machine. The voltage however is kept constant at the controlling synchronous main station, and thus must vary with the load in the induction generator station. Assuming an extreme case, of 10 per cent resistance and 20 per cent reactance in the line from the induction machine station to

the next synchronism station, we get the modified torque curve shown in Fig. 3. As seen, at full load P, there is practically no change; about 4 per cent slip above synchronism. The maximum torque of generator G and motor M, and the torque at the concave part of the induction generator curve, C, have greatly

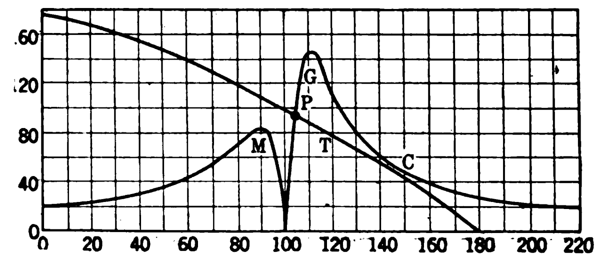


FIG. 3—SMALL HYDROELECTRIC INDUCTION GENERATOR PLANT—CONSTANT VOLTAGE IN SYNCHRONOUS STATION

decreased. However, C is still above T, that is, even under this extreme assumption, the induction generator would pull the turbine down from its racing speed of 180, to the normal full load speed of 104, though the margin has become narrow.

Assuming however an induction machine with much less slip,

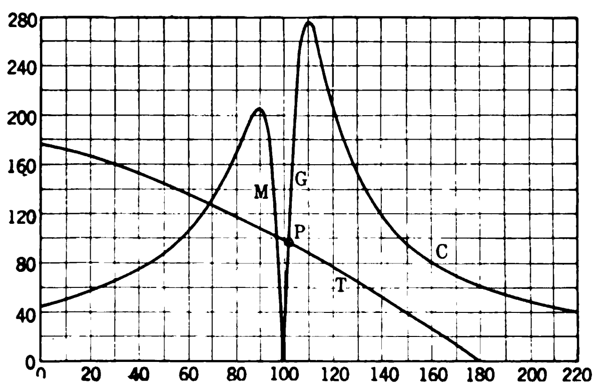


FIG. 4—LARGE HYDROELECTRIC INDUCTION GENERATOR PLANT—CONSTANT TERMINAL VOLTAGE

with only half the rotor resistance of Figs. 2 and 3. At constant terminal voltage, this gives the curves shown in Fig. 4. The full load P is at speed 102, or 2 per cent above synchronism, and while the curve branch C is much lower, the conditions are still perfectly stable. Assuming however, with this type of low

resistance rotor, a high line impedance, 10 per cent resistance and 20 per cent reactance, as in Fig. 3. We then get the condition shown in Fig. 5. The range C drops below T, and the induction generator torque curve G intersects the turbine torque curve T at three points: P, P_1 and P_2. Of these three theoretical running speeds, $P = 102$, $P_1 = 169$ and $P_2 = 113.5$, two are stable, P and P_1; while the third one, P_2, is unstable, and from P_2, the speed must either decrease, reaching stability at the normal full load point P, or the machine speed up to P_1.

If with the conditions represented by Fig. 5, the turbine should—by an opening of the circuit for instance—have speeded up to its free running speed 180, closing the circuit does not bring the speed back to normal, P, but the machines slow down only to speed P_1, where stability is reached, at very little output and very large lagging currents in the induction generator. To

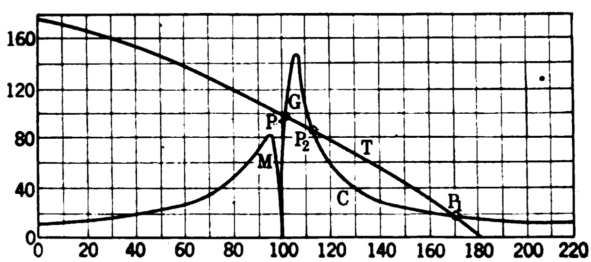


FIG. 5—LARGE HYDROELECTRIC INDUCTION GENERATOR PLANT—CONSTANT VOLTAGE IN SYNCHRONOUS MAIN STATION

restore normal condition then would require shutting off the water, at least sufficiently to drop the turbine torque curve T below C, and then letting the machines slow down to synchronism. They would not go below synchronism, even with the water gates entirely closed, as the induction machine as a motor, on curve M, holds the speed.

A solution in the case Fig. 5 would be the use of a simple excess speed governor, which cuts off the water at 5 to 10 per cent above synchronism.

However, the possibility of difficulty due to the "dropping out of the induction generator" as we may call it in analogy to the dropping out of the induction motor, are rather less real than it appears theoretically. In smaller stations, such as would be operated without attendance, as automatic stations, the torque curve of the induction generator, as a small machine, would be

of the character of Figs. 2 and 3, and thus not liable to this difficulty. The low resistance type of induction machines, as represented in Figs. 4 and 5, may be expected only with the larger machines, used in larger stations. In those, some attendant would be present to close the water gates in case of the circuit breakers opening, or a simple cheap excess speed cut-off would be installed at the turbines, keeping them within 10 per cent of synchronism, and within this range, no dropping out of the induction generator can occur.

It is desirable however to realize this speed range of possible instability of the induction generator, so as to avoid it in the design of induction generators and stations.

APPENDIX

Collection of Fuel Power by Steam Turbine Induction Generator

A. The Automatic Steam Turbine Induction Generator Station

The same reason which in the preceding led to the conclusion that in the (automatic) induction generator station is to be found the solution of the problem of collecting the numerous small amounts of hydraulic energy, which are scattered throughout our country along creeks and mountain streams, also applies, and to the same extent, to the problem of collecting the innumerable small quantities of mechanical or electrical energy, which are, or can be made available wherever fuel is consumed for heating purposes. Of the hundred millions tons of coal, which are annually consumed for heating purposes, most is used as steam heat. Suppose then, we generate the steam at high pressure—as is done already now in many cases for reasons of heating economy—and interpose between steam boiler and heating system some simple form of high pressure steam turbine, directly connected to an induction generator, and tie the latter into the general electrical power distribution system. Whenever the heating system is in operation, electric power is generated, as we may say as "by-product" of the heating plant, and fed into the electric system.

The power would not be generated continuously, but mainly in winter, and largely during the day and especially the evening. That is, the maximum power generation by such fuel power collecting plant essentially coincides with the lighting peak of the central station, thus occurs at the time of the day, and the season when power is most valuable. The effect of such fuel

power collection on the central station should result in a material improvement of the station load factor, by cuttnig off the lighting peaks.

The only difference between such steam turbine induction generator stations, collecting the available fuel power scattered throughout the cities and towns, and the hydraulic induction generator stations collecting the powers of the streams throughout the country, is that in the steam turbine plant an excess speed cut-off must be provided, as the free running steam turbine speed is usually not limited to less than double speed, as is the case with the hydraulic turbine. Otherwise however, no speed governing is required. A further difference is, that the greater simplicity and therefore lower investment of the steam turbine plant would permit going down to smaller powers, a few kilowatts perhaps.

It is interesting to note, that even with a very inefficient steam turbine, the electric generation of such fuel power collecting plant interposed between boiler and heating system, takes place with practically 100 per cent efficiency, because whatever energy is wasted by the inefficiency of the steam turbine plant, remains as heat in the steam, and the only loss is the radiation from turbine and generator, and even this in most cases is useful in heating the place where the plant is located. The only advantage of a highly efficient turbine, is that larger amounts of electric power can be recovered from the fuel, and the question thus is that between the investment in the plant, and the value of the recovered power.

If then the total efficiency, from the chemical energy of the fuel to the electric power, were only 3 per cent, it would mean that 3 per cent more coal would have to be burned, to feed the same heat units into the heating system. At an average energy value of 30,000 kj. per kg. of coal, this would give per ton of coal, 900,000 kj. or 250 kw-hr. At a bulk value of ½ cent per kw-hr. it would represent a power recovery value of $1.25 per ton of coal. This is quite considerable, more than sufficient to pay the interest on the investment in the very simple plant required.

At first, the steam turbine induction generator plant, proposed for the collection of fuel power, would appear similar to the isolated plant which, though often proved uneconomical, still has successfully maintained its hold in our northern latitudes, where heating is necessary through a considerable part of the year. However, the difference between the steam turbine in

duction generator plant and the isolated steam electric plants in our cities, is the same as that between the automatic hydroelectric induction generator station, and the present standard synchronous generator station: by getting rid of all the complexity and complication of the latter, the induction generator station becomes economically feasible in small sizes; but it does so only by ceasing to be an independent station, by turning over the functions of regulation and control to the central main station and so becoming an adjunct to the latter. But by this very feature, the turbo induction generator plant might afford to the central station, the public utility corporation, a very effective means of combatting the installation of isolated plants, by relieving the prospective owner of the isolated plant of all trouble, care and expense and incidental unreliability thereof, supplying central station power for lighting, but at the same time utilizing the potential power of the fuel burned for heating purposes. The simplest arrangement probably would be, that the fuel power collecting plants scattered throughout the city would, as automatic stations, be taken care of by the public utility corporation, their power paid at its proper rates, those of uncontrolled bulk power, while the power used for lighting is bought from the central station at the proper lighting rates.

As this however means a new adjustment of the relation between customer and central station, and is not merely an engineering matter like the hydroelectric power collection, I have placed it in an appendix.

B. Discussion

We realize that our present method of using our coal resources is terribly inefficient. We know that in the conversion of the chemical energy of coal into mechanical or electrical energy, we have to pass through heat energy and thereby submit to the excessively low efficiency of transformation from the low grade heat energy to the high grade electrical energy. We get at best 10 to 20 per cent of the chemical energy of the coal as electrical energy; the remaining 80 to 90 per cent we throw away as heat in the condensing water, or worse still, have to pay for getting rid of it. At the same time we burn many millions of tons of coal to produce heat energy, and by degrading the chemical energy into heat, waste the potential high grade energy which those millions of tons of coal could supply us.

It is an economic crime to burn coal for mere heating without

first taking out as much high grade energy, mechanical or electrical, as is economically feasible. It is this feature, of using the available high grade energy of the coal, before using it for heating, which makes the isolated station successful, though it has every other feature against it. To a limited extent, combined electric and central steam heating plants have been installed, but their limitation is in the attempt to distribute heat energy, after producing it in bulk, from a central station. Here again we have the same rule; to do it efficiently, do it electrically. In the efficiency of distribution or its reverse, collection, no other form of energy can compete with electric energy, and the economic solution appears to be to burn the fuel wherever heating is required, but first take out its available high grade energy, and collect it electrically.

Assume we use 200 million tons of coal per year for power, at an average total efficiency of 12 per cent, giving us 24 million kw. (referred to 24-hr. service) and use 200 million tons of coal for heating purposes, wasting its potential power.

If then we could utilize the waste heat of the coal used for power generation, even if thereby the average total efficiency were reduced to 10 per cent, we would require only 240 million tons of coal, for producing the power, and would have left a heating equivalent of 216 million tons of coal, or more than required for heating. That is, the coal consumption would be reduced from 400 million to 240 million of tons, a saving of 160 million tons of coal annually.

Or, if from the 200 million tons of coal, which we degrade by burning it for fuel, we could first abstract the available high grade power, assuming even only 5 per cent efficiency, this would give us 10 million kw. (24-hr. rate), at an additional coal consumption of 10 million tons, while the production of the 10 million kw. now requires 100 million tons of coal, more or less, thus getting a saving of 90 million tons of coal; or putting it the other way, a gain of 9 million kw.—12 million horse power—24-hr. service, or 36 million horse power for an 8-hr. working day.

It is obvious that we never could completely accomplish this; but even if we recover only one-quarter, or even only one-tenth of this waste, it would be a vast increase in our national efficiency.

Thus the solution of the coal problem, that is, the more economic use of fuel energy, is not only the increase of the thermodynamic efficiency of the heat engine, in which a radical advance

Per ton of coal: Chemical energy, 30 × 10^6 kj: Heat energy of steam from boiler, at 75 per cent. boiler efficiency, 22.5 × 10^6 kj.

	Boiler press		Dist. press		Carnot-efficiency per cent.	Output at 50 per cent. efficiency		Value of power at ½c. per kw-hr. $..	Avg. kw., assuming 25% time of use	Tons of coal per kw.	Size of induction generator, per 100 tons coal annually
	atm:	lb.	atm:	lb.		kj. × 1000	kw-hr.				
Steam Heating	6	90	1.25	19	12.3	1380	385	1.92	0.176	5.7	25 kw.
	15	220	1.25	19	19.8	2230	620	3.10	0.283	3.5	45 kw.
Vacuum Heating	6	90	0.48	7	18.1	2030	565	2.82	0.258	3.9	40 kw.
	15	220	0.48	7	25.0	2820	810	4.05	0.37	2.7	55 kw.

is limited by formidable difficulties; but is the recovery of the potential energy of all the fuel, by electric collection.

C. Turbo Induction Generator

Assume then that wherever fuel is burned to produce steam for heating purposes, instead of a low-pressure boiler giving a few pounds over-pressure only, we generate the steam at high pressure, at six atmospheres (90 lbs.) or, in larger plants, even at 15 atmospheres (220 lb.) passing the steam through a high pressure turbine wheel directly connected to an induction generator tied into the electric supply system, and then exhaust the steam at 1.25 atmospheres (19 lb.) into the steam heating system, or at 0.48 atmospheres (7 lb.) into a vacuum heating system.

At a fuel value of the coal of 30,000 kj. per kg. we have (see table)

From this it would follow that the average magnitude of the steam turbine induction generator plant for power collection from fuel in heating plants, would be about one-quarter to one-half kw. per ton of coal burned annually, under the assumption, that the use of the heating plant is equivalent to full capacity during one quarter of the time, and the turbine induction generator plant 50 per cent larger, to take care of maximum loads.

As seen, the value of the recovered power would be a substantial percentage of the fuel cost.

With 100 million tons of coal used for heating purposes annually, assuming an average recovery of 600 kw-hr. per ton, this gives a total of 60,000 million kw-hr. per year. One-quarter of this is more electric power than is now produced at Niagara, Chicago, New York and a few other of the biggest electric systems together.

To be presented at the 34th Annual Convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 28, 1918.

PROTECTION FROM FLASHING FOR DIRECT CURRENT APPARATUS

BY J. J. LINEBAUGH AND J. L. BURNHAM

ABSTRACT OF PAPER

The equipment developed for the protection of direct-current apparatus as described in this paper is applicable to all direct-current apparatus and all methods of operation. Special means of protection for use only with particular apparatus or conditions of operation have not been mentioned. The principal steps in the experimental development of high-speed circuit breakers and flash barriers are briefly given.

The protection afforded by the high-speed breaker or barriers is sufficient for most apparatus and service, but *complete* protection for *any* direct-current apparatus and service requires both the high-speed breaker and flash barriers. Attention is directed to the importance of arranging the connections to the brush rigging so that the magnetic action on the arc will be a minimum, and properly directed, so the flash will do the least damage.

THE problem of protection from flashing has for many years confronted engineers who build and operate direct-current machines. Numerous schemes and suggestions have been put forward which it was hoped would overcome the tendency to flashover on extra heavy overloads or short circuits. Some time ago it was felt that the subject of prevention and protection from flashing has not received the study and investigation justified by the trouble experienced and it was decided to make a comprehensive study of the entire subject.

Some form of barrier has been the most common protection suggested, and different forms have been tried with a slight degree of success on some machines and absolute failure on others. It was the opinion of many engineers that barriers could not be designed to take care of a short circuit and that their value was doubtful. However, a special form of barrier, which gives the required protection, will be described later.

It was realized that the means for prevention of flashing at the commutator and brushes of direct-current machines must operate to remove the cause very quickly. The use of some form of high-speed device, which would open the circuit or insert re-

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sistance before the short circuit current could reach a value which would cause flashing, seemed the most logical way to solve the problem, although it was appreciated that the action of the device must be much more rapid than any commercial circuit-opening device previously produced. An investigation was conducted along these lines and two distinct types of high-speed breakers developed, which will be described separately.

A flash at the commutator starts from excessive sparking. Sparking is produced by the breaking of current in the coils short-circuited by the brush as each segment of the commutator passes from under the brush. As the coil is inductive, the spark or arc tends to hold and, if the arc is of sufficient volume, the vapor produced thereby forms a low resistance path between segments and from brush to brush or to frame; through which a large current may pass. See Figs. 1 and 2.

Sparking may be prevented by providing a magnetic field of proper strength and distribution to influence the coils during reversal of their current as they pass through short circuit by the brushes. To provide the correct commutating field for all conditions of load has been the object of designers but success has been only partial. At high loads, saturation of magnetic circuits and distorting influence prevent attainment of the desired field, and for sudden changes in load the changes in field cannot be properly synchronized. It is more difficult to avoid sparking with rapidly varying loads than with gradually changing or steady load, but if a sudden load which would cause flashing is of short enough duration, the arcing at brushes may not produce enough conducting vapor to establish an arc supported by the main voltage. *The value of load that causes flashing when applied suddenly (short circuit) is a function of the time required to throw it off.* The quicker the circuit is opened the higher the value of current that will not cause arcing.

With the ordinary circuit breaker which begins to open in about 0.15 second, there is a certain maximum load which cannot be exceeded for each commutating machine without causing flashing. If feeders have sufficient resistance to limit the short-circuit current to this critical value, flashing will occur only on the rare occasion of a short circuit in a feeder itself. See Fig. 3. It has been the standard practise of nearly all manufacturers to recommend tapping the feeders, especially railway feeders, at a sufficient distance from the substation to insure enough resistance in the circuit to limit current in case of short circuit near the station.

Inductance may be added to the circuit to retard the rate of increase of current on short circuit to such an extent that the ordinary breaker will have time to trip before the current in the machine reaches a value that would cause flashing. The amount of inductance required to delay the rise in current sufficiently, however, introduces other disadvantages which make its use undesirable. When the current is interrupted, the increase in voltage from inductive "kick" is difficult for circuit breakers to handle and introduces the possibility of applying dangerous voltage stresses to the apparatus.

Reactors have been tried in a few instances with some success but it has always been a mooted question whether the resistance of the reactor did not give as much or more protection than the inductance of the coil, and if this is the case resistance only would be much cheaper to install. A coil to give the delay required is usually very large and expensive and occupies much valuable space, giving a total cost out of proportion to the cost of the machines protected or the protection obtained.

With special high-speed circuit-opening devices operating in about 0.005 second, the more sensitive machines, such as 60-cycle synchronous converters for railway voltages, may be short-circuited without flashing over, even though the maximum current is of higher value than would cause flashing with suddenly applied load and ordinary circuit-breaker protection.

The speed at which a circuit breaker must operate to prevent flashing depends on the amount of load thrown on the machine but, under worst conditions, our tests seem to confirm that it must be *quicker* than one half cycle of the machine to be protected. The time of operation of the breaker would be measured between the time that the current reaches the flashing value to the time that the current is again reduced to the same value after the breaker opens. If the arc formed between two segments is not blown out as they pass from one set of brushes to the next and all following segments have similar arcs formed between them, the arc would completely bridge between positive and negative brushes in one-half cycle, which would complete the flashover. Complete flashover might also occur from gases being blown by windage, magnetically, or by expansion, to increase or decrease the half cycle time.

The time of operation of circuit breakers as given herein is measured from the beginning of short circuit to the instant the breaker begins to reduce the current rise.

Investigation covering these several schemes of protection was made, which it is believed will be of interest and will be described briefly with oscillograms, reproductions from photographs, etc., showing behavior under different loads and short-circuit conditions.

All short-circuit tests were made by connecting positive and negative terminals with a 500,000 circular mil cable; the only equipment in the circuit being the necessary current shunt for the oscillograph, a contactor to close the circuit, and a circuit breaker for overload protection, in addition to the protective device being investigated. Power for the 300-kilowatt, 25-cycle and 500-kilowatt, 60-cycle, 600-volt synchronous converters, used in fuse, barrier, reactor, and high-speed circuit breaker tests, was supplied from a 6000-kilowatt frequency changer set only a few feet from the test, so that there was very little drop in the voltage of the generator or from resistance, and the oil switch was set so that it did not trip out.

High Speed Circuit Breaker

At the time this development was started it was felt that if a circuit breaker could be designed to operate *within* the time required for a commutator bar to pass from one brush to another; that is, within one half cycle, protection would be afforded against practically any short circuit. Designs were therefore begun on a circuit breaker which would open within 0.007 second, which would cover most commercial machines; *i.e.*, for 60 cycles and lower frequency.

High-speed breakers had been suggested and attempts made to produce such devices previous to this time but, as far as the writers know, had never been made to obtain as high speed as the discussion shows would be necessary.

Different types of construction were studied and samples of several preliminary models constructed without obtaining the speed desired. One of the most promising types of construction considered consisted of a knurled fly wheel operating continuously with a knurled cam, so designed and located that a current relay would insert a wedge between the wheel and the cam and trip a breaker attached to the cam by suitable toggle mechanism. This preliminary sample indicated that 0.035 second was the best speed that could be attained.

It was then decided to concentrate all energies on a circuit breaker using the well known principle of a latch, heavy spring

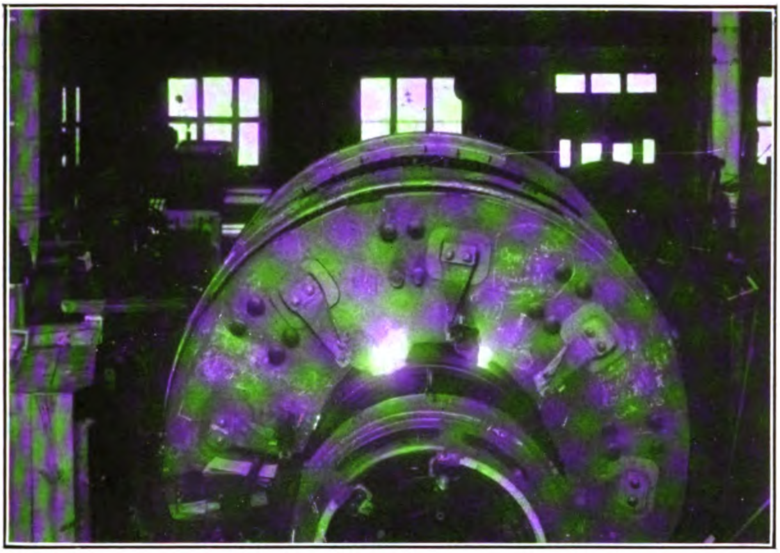


FIG. 1

Flashing at brushes on 1000-kw., 1500-volt generator forming part of 2000-kw., 3000-volt motor-generator set at five times load, showing different stages of arc formation.

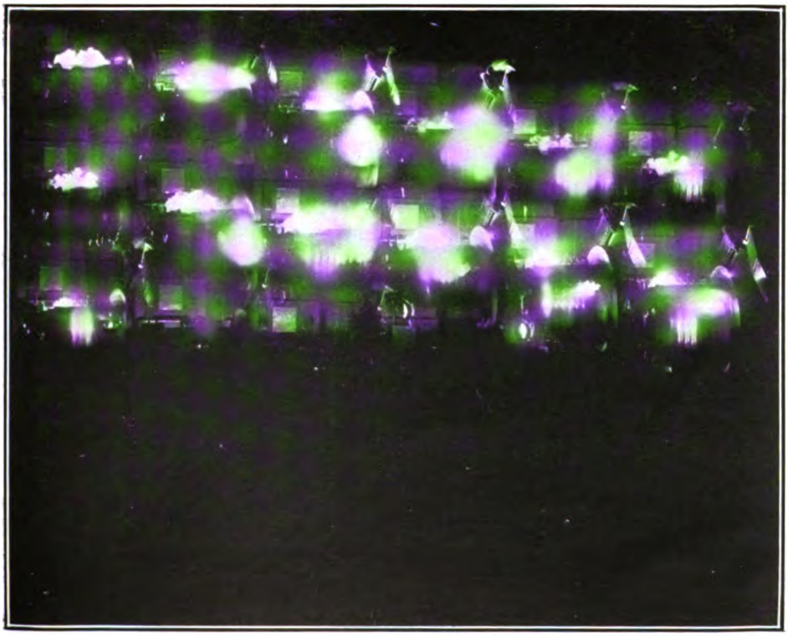


FIG. 2 [LINEBAUGH AND BURNHAM]

High-speed photograph of flashing on 300-kw., 600-volt, 25-cycle synchronous converter with short circuit on 0.015 ohms additional in the external circuit and standard circuit breaker.

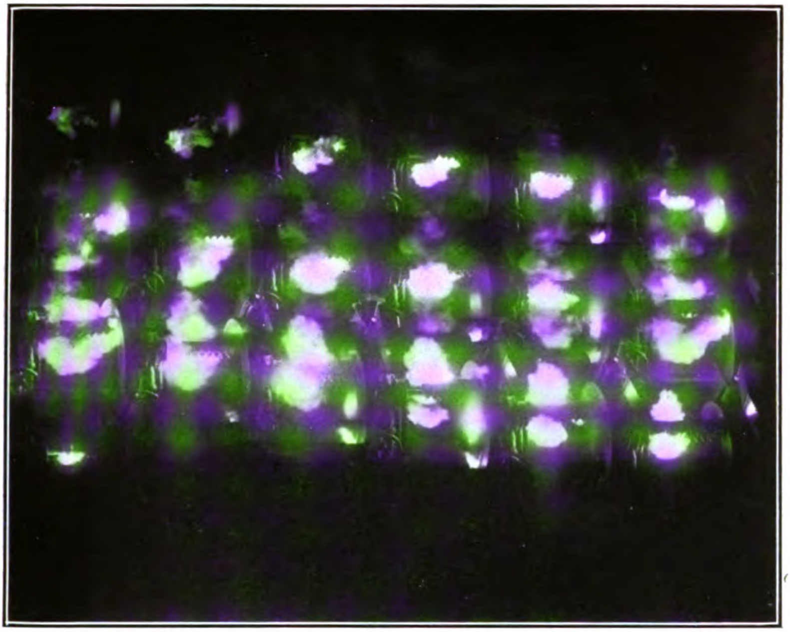


FIG. 3

High speed photograph of short circuit on 300-kw., 600-volt, 25-cycle, synchronous converter with standard circuit breaker.

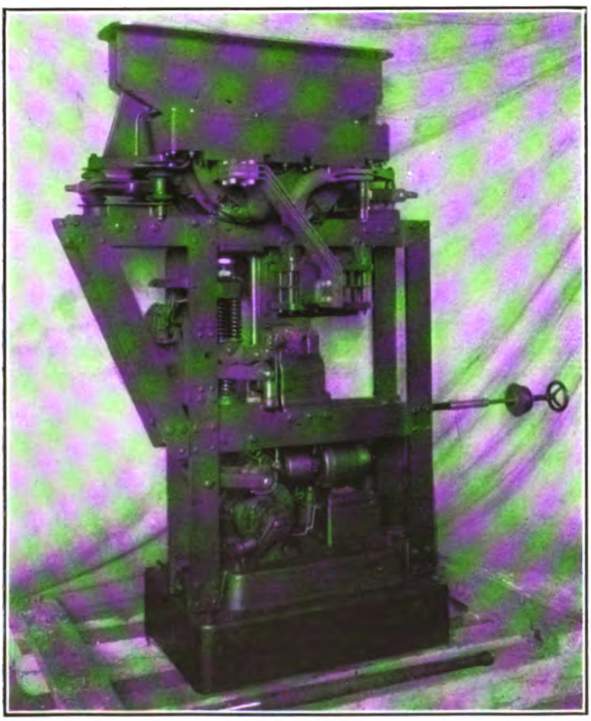


FIG. 4 [LINEBAUGH AND BURNHAM]

3000-ampere, 3600-volt, direct-current high-speed circuit breaker.

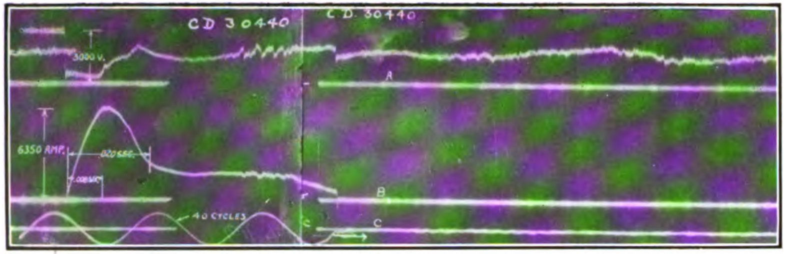


FIG. 5

Direct-current short circuit on 2000-kw., 3000-volt, motor-generator set with high-speed circuit breaker and standard 3000-volt switchboard type circuit breaker.

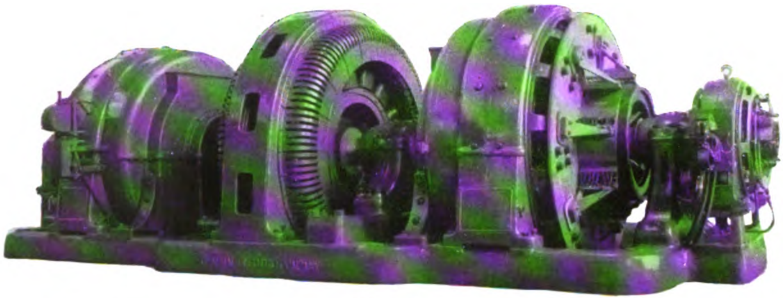
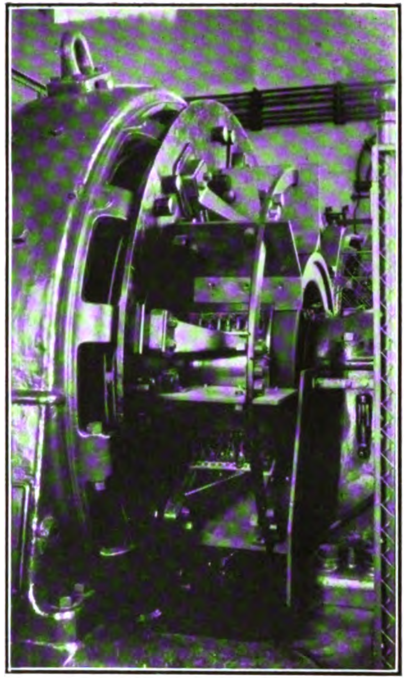


FIG. 6

2000-kw., 3000-volt, direct-current synchronous motor-generator set before assembly of flash-barriers.



[LINEBAUGH AND BURNHAM]

FIG. 7

Type of flash barrier installed on 2000-kw., 3000-volt, synchronous motor-generator set used in connection with high-speed circuit breaker.

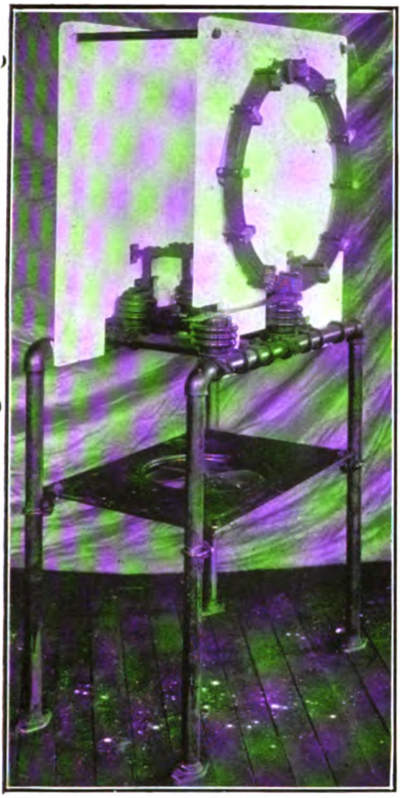


FIG. 9
High-speed air cooled fuse holder with magnetic blow-out used in test.

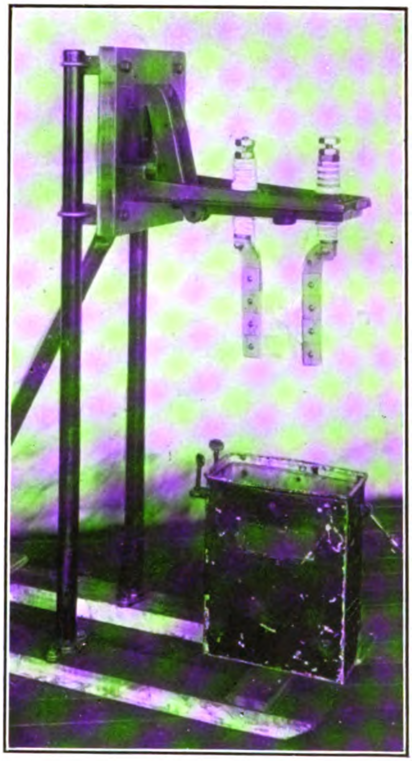


FIG. 10
High-speed oil-cooled fuse holder, used in test.

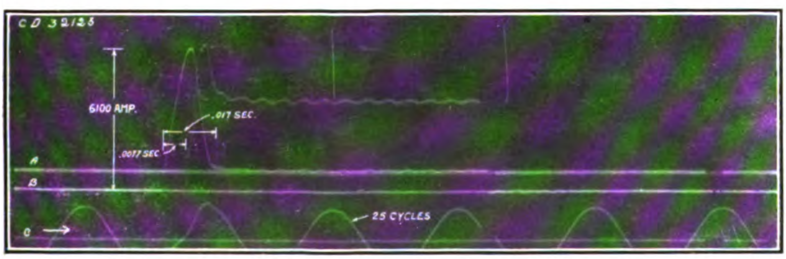


FIG. 11 [LINEBAUGH AND BURNHAM]

Short circuit on 300-kw., 600-volt, 25-cycle, synchronous converter protected by air-cooled high-speed fuse. Curve A, voltage across fuse; Curve B, line current; Curve C, collector-ring voltage.

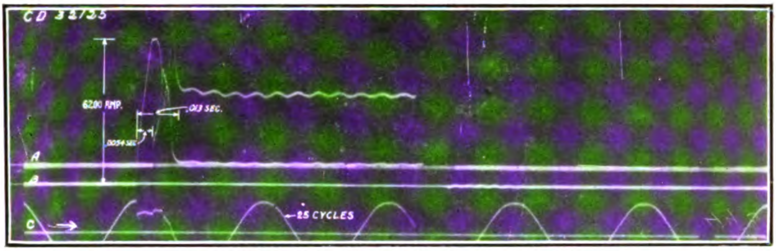


FIG. 12

Short circuit on 300-kw., 600-volt, 25-cycle, synchronous converter protected by oil-cooled high-speed fuse. Curve A, voltage across fuse; Curve *B*, line current; Curve *C*, collector-ring voltage.

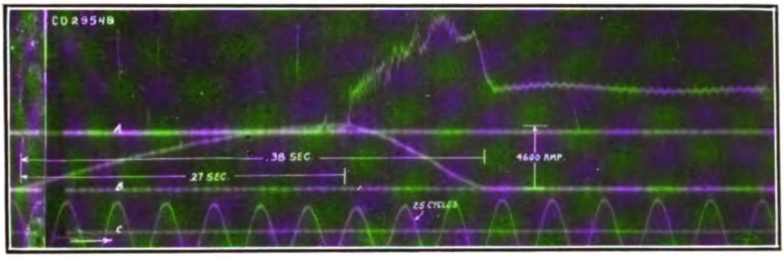


FIG. 13

Short circuit on 300-kw., 600-volt, 25-cycle, synchronous converter protected by air-core reactor in direct-current circuit and standard circuit breaker. Curve *A*, voltage across circuit breaker; Curve *B*, line current; Curve *C*, collector-ring voltage.

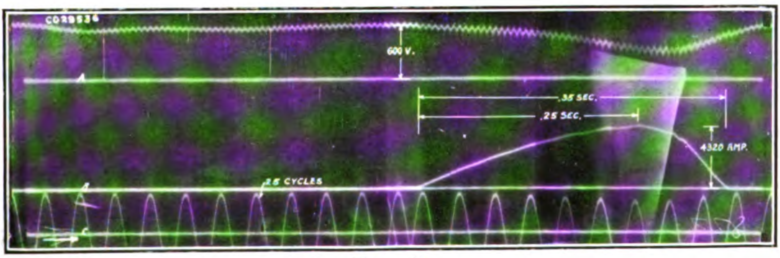


FIG. 14

Short circuit on 300-kw., 600-volt, 25-cycle, synchronous converter protected by air-core reactor in direct-current circuit and standard circuit breaker; Curve-*A*, voltage across armature; Curve *B*, line current; Curve C, collector-ring voltage.

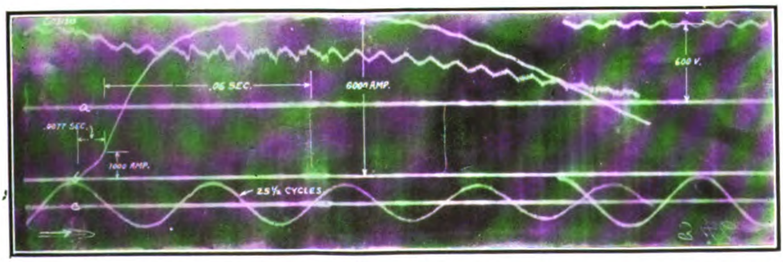


FIG. 15 [LINEBAUGH AND BURNHAM]

Short circuit on 300-kw., 600-volt, 25-cycle, synchronous converter, protected by iron-core reactor in direct-current circuit and standard circuit breaker. Curve *A*, voltage across the armature; Curve *B*, line current; Curve *C*, collector-ring voltage.

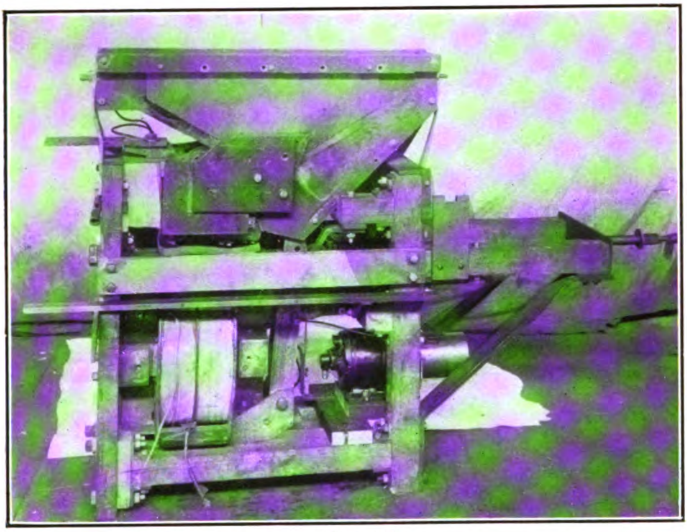


FIG. 16

Second form of high-speed circuit breaker, capacity 1500 amperes, 600 volts.

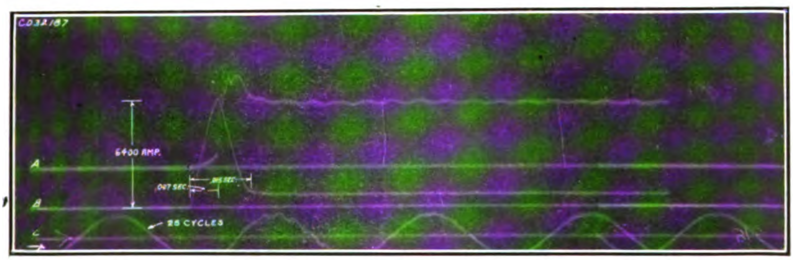


FIG. 17

Short circuit on 300-kw., 600-volt, 25-cycle synchronous converter protected by second form of high-speed circuit breaker. Curve A, voltage across circuit breaker; Curve B, line current; Curve C, collector-ring voltage.

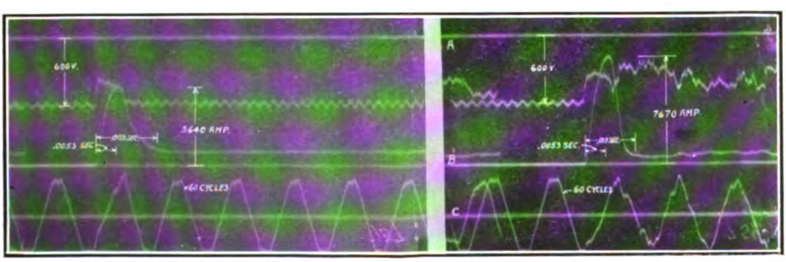


FIG. 18 [LINEBAUGH AND BURNHAM]

Short circuit on 500-kw., 600-volt, 60-cycle, synchronous converter protected by second form of high-speed circuit breaker.

Left hand curve
Load of 0.03 ohms

Right hand curve
Short circuit.

Curve A, armature volts
" B, line current
" C, collector-ring voltage.

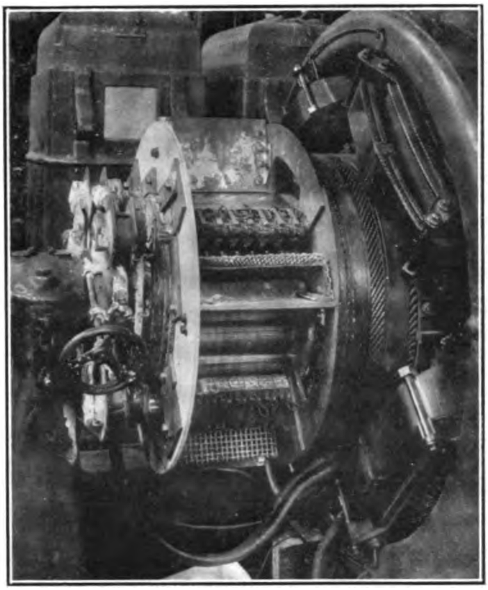


FIG. 19

Final development of flash barriers on 300-kw., 25-cycle, 600-volt synchronous converter.

FIG. 20 [LINEBAUGH AND BURNHAM]

Short circuit on 300-kw., 25-cycle, 600-volt, synchronous converter protected by flash barriers and standard circuit breaker.

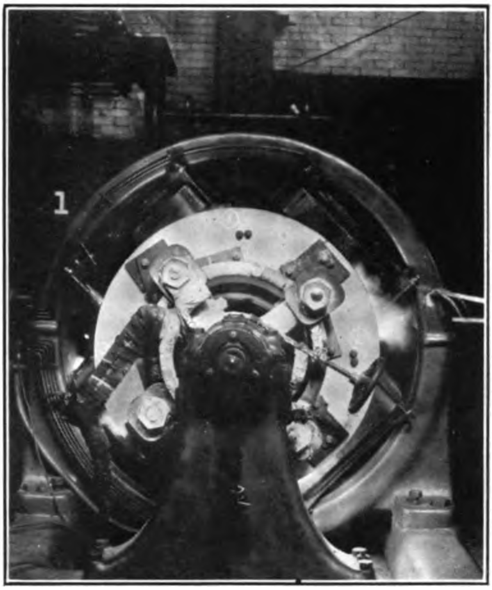


FIG. 21

Short circuit on 300-kw., 25-cycle, 600-volt synchronous converter protected by flash barriers and standard circuit breaker.

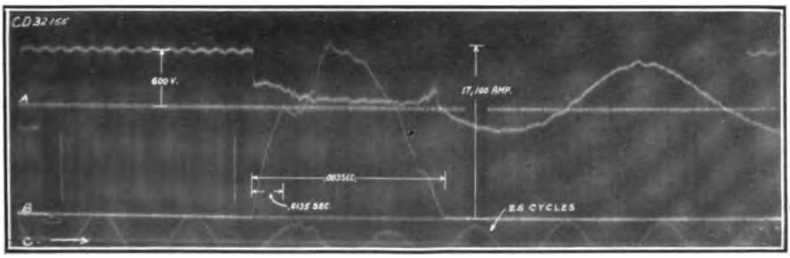


FIG. 22 [LINEBAUGH AND BURNHAM]

Short circuit on 300-kw., 600-volt, 25-cycle, synchroous converter equipped with flash barriers and standard circuit breaker. Curve A, armature volts; Curve B, line current; Curve C, collector-ring voltage.

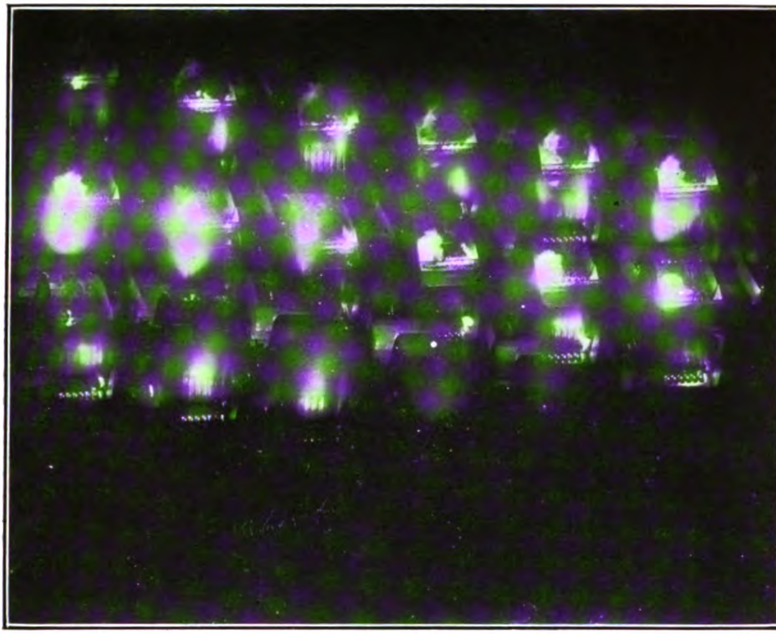


FIG. 23
High-speed photograph of short circuit on 300-kw., 600-volt 25-cycle synchronous converter protected by flash barriers and standard breaker.

FIG. 24 [LINEBAUGH AND BURNHAM]
High-speed photograph of short circuit on 300-kw., 600-volt, 25-cycle, synchronous converter protected by flash barriers and standard circuit breakers.

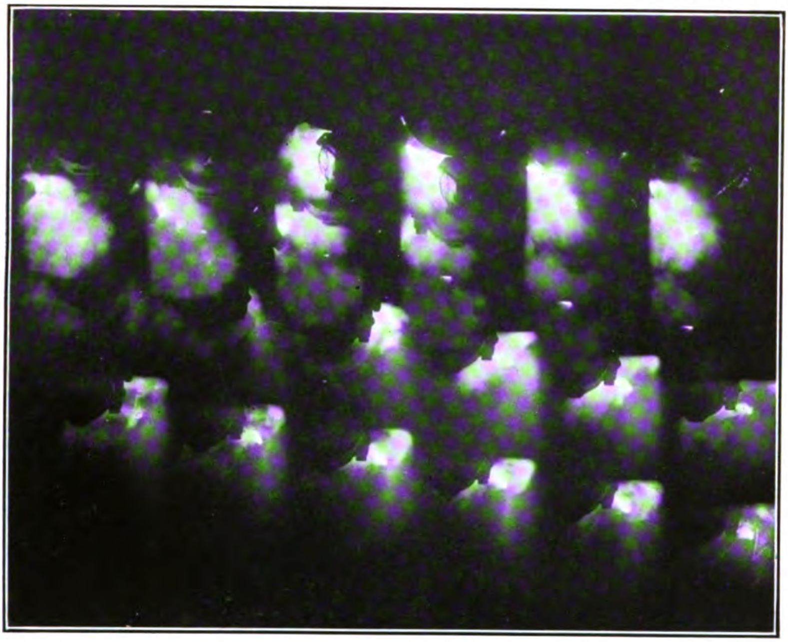


FIG. 25
High-speed photograph of short circuit on 500-kw., 600-volt, 60-cycle synchronous converter without protection.

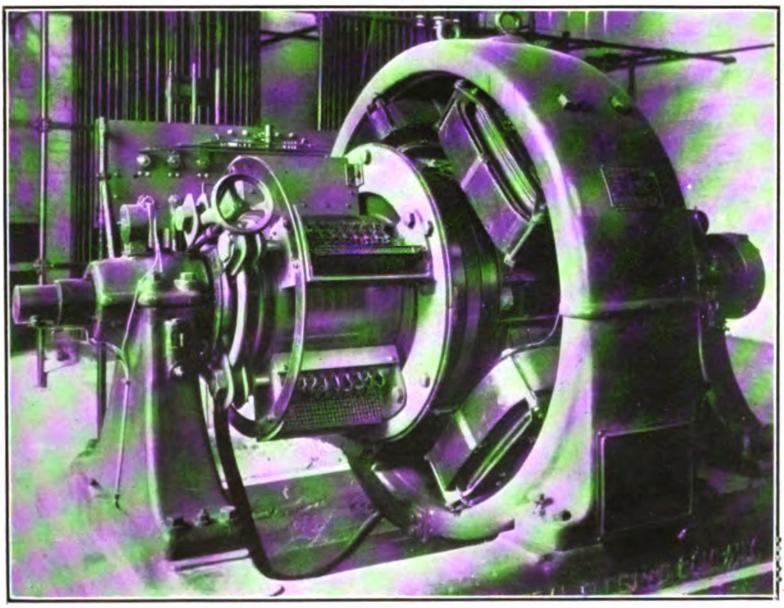


FIG. 26 [LINEBAUGH AND BURNHAM]
500-kw., 25-cycle, 600-volt, synchronous converter, installed in automatic substation, equipped with commercial form of flash barrier.

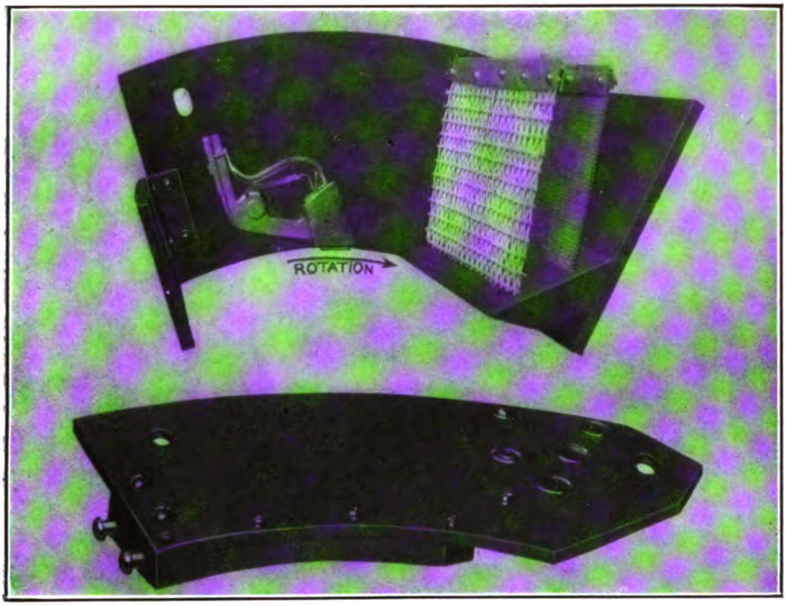


FIG. 27

Flash barrier with front removed to show location and construction of arc scoop and wire-mesh arc coolers.

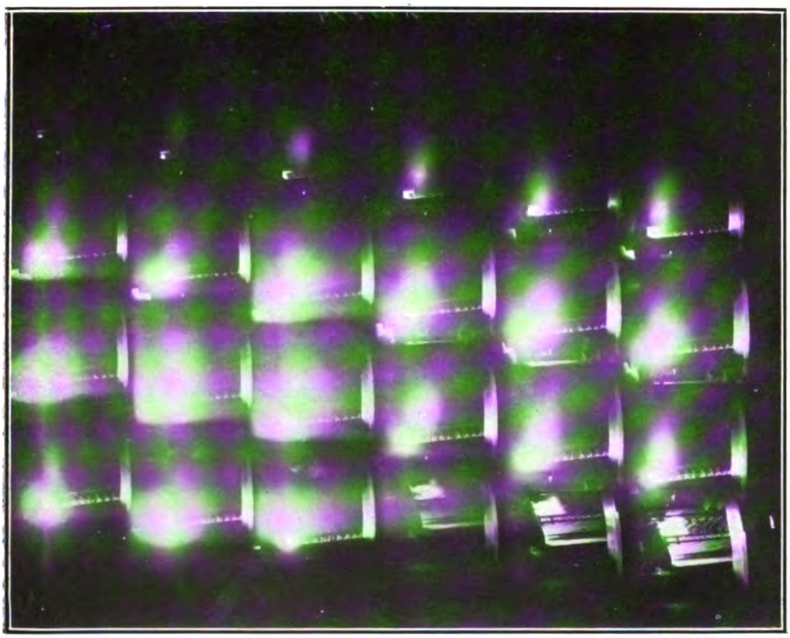


FIG. 28 [LINEBAUGH AND BURNHAM]

High-speed photograph of short circuit on 500-kw., 600-volt, 60-cycle, synchronous converter with flash barriers and standard circuit breaker with preliminary arrangement of brush rigging. Arc at outer end of commutator.

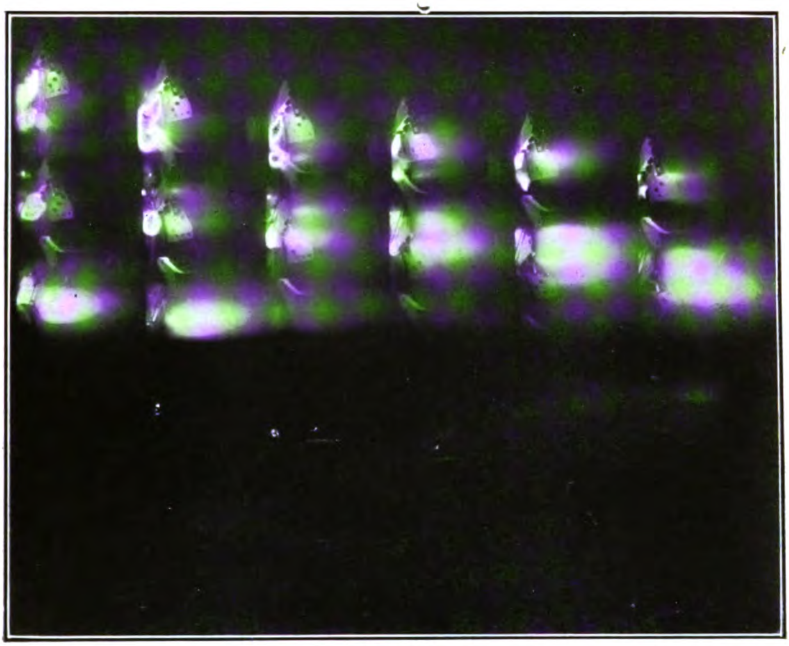


FIG. 29

High-speed photograph of short circuit on 500-kw., 600-volt, 60-cycle synchronous converter with flash barriers and standard circuit breaker with preliminary arrangement of brush rigging. Arc at outer end of brush rigging.

FIG. 30 [LINEBAUGH AND BURNHAM]

High-speed photograph of short circuit on 500-kw., 600-volt, 60-cycle synchronous converter protected by flash barriers and standard circuit breaker after arrangement of brush rigging has been changed. Uniform distribution of flashing.

and series tripping coil, and the high speed breaker shown in Fig. 4 was finally built.

The problem was to obtain very quick tripping, rapid acceleration of contacts and a sufficient number of ampere turns in the magnetic blowout to insure rapid breaking of the arc. Previous ideas of design had to be abandoned when working for such high speed when a loss of 0.001 second meant a very serious increase in time of operation.

It was found that a series blowout coil had to be used, as sufficient time could not be allowed for the building up of a field after the contacts opened as is ordinarily done in circuit-breaker design, and the strength of this coil must be many times that usually used to rupture the circuit by giving the quick start and acceleration to the arc necessary for the speed desired. The breaker in question has a total of about 150,000 ampere turns at the maximum current obtained.

The moving parts must all be as light as possible, consistent with the great strength required, so that they can be started, accelerated and stopped in a very short space of time and distance. Even with this type of construction, it was found necessary to use somewhat high spring pressure; the spring being compressed to about 8000 pounds when the breaker was closed and ready for tripping.

A very special latch with very small tripping movement was designed somewhat similiar to the hair trigger on a rifle, in connection with a special high-speed tripping coil so that about 0.001 inch movement of the plunger would trip the breaker. It will assist in appreciating the speed attained when it is noted that the breaker must be arranged so that it will not trip under ordinary load condition and must be set above the tripping point of the regular substation breaker so that it will act while the current is increasing from say three and one-half times load to eight times load; current rising at the rate of about 1,000,000 amperes per second. Fig. 5 gives a very good idea of speed and limiting of current, from which it will be seen that the breaker starts to insert resistance in about 0.008 second and the load on the machine is reduced well below the flashing value in 0.020 second after the short circuit was applied.

A breaker was tested very exhaustively in connection with a 2000-kilowatt 3000-volt direct-current synchronous motor-generator set shown in Fig. 6, built for the Chicago, Milwaukee & St. Paul electrification, and found to give complete protection

from damage or burning on short circuit when equipped with barriers shown in Fig. 7.

In connection with the test, it was found that even the speed of 0.008 second obtained would not completely protect machines from flashing on the most severe short circuit, and barriers shown were designed and installed. Tests referred to with high-speed breakers were taken with these barriers, which will be described later.

It is evident that it is preferable in case of short circuit to insert resistance by a high-speed breaker to quickly limit the current to some conservative value and then open the circuit. This type of protection has been adopted as standard. All tests, investigations, etcetera, were based on this theory, although some tests were taken by opening the circuit. It was found that there was a greater tendency for machine to flash if the circuit was opened completely at one time or if too high resistance was inserted, reducing the load to too low a value. For the sake of convenience and comparison, all tests were made throwing short circuit on the machine without load.

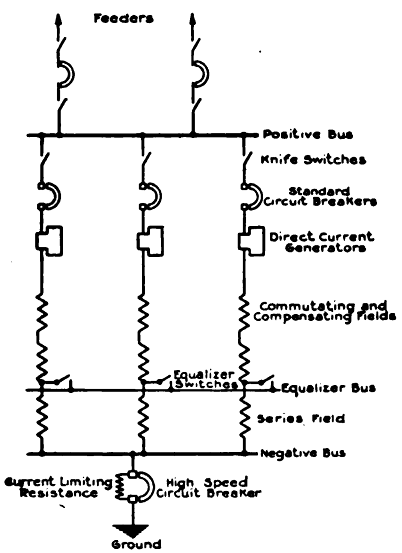


FIG. 8

Diagram of direct-current connections for substation equipped with three motor-generator sets protected by one high-speed circuit breaker connected across limiting resistance

Some of these breakers have been in service since early in 1917 in the substations of the Chicago, Milwaukee & St. Paul Railroad and have amply justified the faith of the railroad company and the designers, as they protect the apparatus from all short circuits experienced, although all feeders are tapped directly to the overhead trolley system immediately at the substation.

One of these breakers is installed in each of the substations connected between the negative bus of the station and the ground or return circuit, as this location gives maximum protection, and one breaker can be used for each machine or one for the entire substation, as shown in Fig. 8.

High Speed Fuse

It is evident that if a fuse could be developed that would melt at a very small increment of current above normal rating, it might be possible to obtain a speed which would limit the current on a short circuit along the same line as the high-speed circuit breaker just described.

A careful study of all available metals was made by Mr. P. E. Hosegood, who suggested using a silver fuse, and a number of silver fuses of different shapes were tried in the special fuse holders shown in Figs. 9 and 10. The oscillograph record, taken with air break fuse and magnetic blow-out, shown in Fig. 11, indicates that a very high speed is obtained, giving excellent protection and duplicating almost exactly the speed of the high-speed circuit breaker. It was found that a short circuit could be thrown on the 300-kilowatt, 25-cycle, 600-volt synchronous converter without flashing over and with very little sparking at the brushes. The oil-immersed fuse holder without magnetic blow-out gave practically the same result (Fig. 12), the operation being slightly better as far as speed was concerned but the mechanical difficulties of replacing the fuse, etc., being greater.

Reactors

Oscillograph records of short circuit on the 300-kilowatt, 25-cycle, 600-volt synchronous converter show an average initial current rise of about 1,300,000 amperes per second. To protect by reactance, the amount required would depend on the rate of circuit-breaker action. With coils made of 1000 feet of 500,000-circular mil cable, wound on cable reels having an inductance of approximately 0.02 henry in circuit, this particular machine could be short circuited without flashing when protected by a breaker opening in about 0.15 seconds.

An examination of records, Figs. 13 and 14, will show the severe duty on the circuit breaker and increase in voltage on the apparatus.

It was suggested that shunting the reactor by resistance might reduce duty on the circuit breaker. The coils were shunted by 14 and by 100 ohms and it was impossible to determine from either observation or oscillograph any effect due to the resistance.

The effect of an iron core in a reactor having an inductance of 0.00105 henry is shown in Fig. 15, from which it will be noted that the iron saturated at about 1000 amperes in about 0.007

seconds, after which the current rises abruptly, being limited only by the inductance of the coil as if there were no iron in its magnetic circuit. The delay of about 0.007, seconds due to the presence of iron in the coil, is far less than the time required for the usual breakers, now in use, to open. The weight of this reactor was 7 per cent of the weight of the synchronous converter and would have to be many times larger to give protection with an ordinary breaker.

Second Form of High-Speed Circuit Breaker

Mr. J. F. Tritle has more recently suggested a design for a high speed circuit breaker which is simple and substantial in construction. This device was built as shown in Fig. 16 and test indicated that the speed was even faster than the large breaker previously described, as will be seen by comparing oscillograms, Fig. 5, on the large breaker, and Fig. 17 taken with the later breaker. This device is essentially a contactor having a laminated structure with electric holding coil and series bucking coil so that it opens when the load current reaches a value sufficient to offset the ampere turns of the holding coil. Tests on the 300-kilowatt, 25-cycle synchronous converter with this device showed that a short circuit could be thrown on the machine without any tendency of the machine to flash over, and the only sparking obtained extended not over one-half inch from the brushes. Similar tests, Fig. 18, on the 60-cycle, 500-kilowatt synchronous converter showed more sparking and, although it protected the machine at times on short circuit, there were other times when the machine flashed over. When the machine was equipped with barriers, dead short circuit could be thrown on with impunity, there being no tendency to flash over and scarcely sufficient sparking to be noticeable.

This later type of high-speed breaker is a part of the more recent equipment being furnished the Chicago, Milwaukee & St. Paul Railway.

Barriers

The barriers shown in Fig. 7 in connection with the description of the high-speed circuit breaker were developed to delay time of flashover, so that the breaker would give complete protection. Such satisfactory and promising results were obtained without the breaker that it was decided to continue investigation to ascertain if it would be possible to devise barriers

that would take care of all short circuits experienced in actual service.

Under certain conditions it might be desirable to supplement rather than replace, appliances already installed or to protect from disturbances other than direct-current load which cause flashing. For instance, a synchronous converter could not be protected by a high-speed direct-current circuit breaker if flashing is caused by a.c. phase displacement. For this reason additional protection, such as barriers, to dissipate the arc when started was also needed.

Many different forms of barriers were tried on the 300-kilowatt, 25-cycle, 600-volt synchronous converter, previously mentioned. With increasing success as improvements were made to meet failures, the barriers shown in Fig. 19 were evolved. These barriers gave complete protection from flashover or damage on short circuit. Fig. 20 shows machine on short circuit giving a good idea of flashing and protection afforded, while Fig. 21 shows clearly the small amount of flash which extends beyond the barrier.

About 65 short circuits were thrown on the 300-kilowatt, 600-volt, 25-cycle machine without burning of brushes, brush connections or rigging, or damages of any kind to commutator or machine. Oscillogram, Fig. 22, shows a record of current reaching 34 times full load and gives a good idea of the protection afforded. Many of these short circuits were applied at very short intervals, even as close as one minute apart, without failure to hold and extinguish the arc when the breaker opened the circuit.

Figs. 23 and 24 are very interesting high-speed pictures of the same short circuit analyzed by means of a special high speed camera devised by Lieut. Chester Lichtenberg, and the successful high speed pictures we are able to show in this paper are mainly due to his efforts. This camera made it possible to obtain as high as 24 complete pictures of one short circuit, while the best results it was possible to obtain with a moving picture camera were two under-exposed and therefore indistinct pictures.

A little explanation is necessary to read these photographs as, due to the construction of the camera, the lower right hand picture is the first picture of the short circuit; the next picture being the one immediately to the left, and so on to the end of the plate; the first picture at the right of the the next row being

the next picture in the same order and until the end of the plate and the number of rows of pictures. These pictures show very clearly the growth of the arc, disposition on commutator and dissipation of the arc as the regular breaker opens. These permanent records eliminated the personal factors of memory and observation and showed the way for changes to give improvements in barriers. Fig. 25 illustrates very clearly what happens if the machine is short circuited without protection.

The general arrangement of a successful barrier, Fig. 26, is shown herewith.

A close fitting box of fire-proof insulating material surrounds each set of brushes and is located so as to give a small clearance between the box and the commutator.

On the side of the box towards which the commutator rotates after leaving the brush is fastened a V-shaped "scoop", Fig. 27, of fire-proof insulating material, preferably having good heat conductivity, pointing toward the brush and having small running clearance from the commutator.

Radially above the scoop, about one inch apart, are two metal screens, one coarse and one fine mesh, through which the arc is successively forced and cooled.

It was found that a moderate amount of material is required to give the necessary thermal capacity to prevent an arc from passing beyond a screen of this kind. The scoop running very close to the commutator with narrow edge and small clearance picks up the arc from the commutator and deflects it into the arc coolers which, from their construction, allow free passage of all gases generated by the arc. The cooling and condensing of the arc reduces the gas pressure so that shields at the end of the commutator, to prevent the arc being thrown from the end of the commutator and communicated to pillow block and frame, are permissible. It will be noted from the illustrations that the commutators extend beyond the end of the barrier as it was found that the arc must be prevented from being communicated to the end of the bars.

Investigation was then transferred to a 500-kilowatt, 60-cycle, 600-volt synchronous converter and barriers of similar type, but without continuous end shields, were tried.

Tests showed that these barriers did not give protection on short circuit although they prevented machine from flashing over on very high overload. The high-speed camera record in-

dicated that the arc was being thrown to the outer end of the commutator for some reason, causing such high gas pressure at the outer end of the commutator that the arc was blown under the barrier and the machine flashed over. Figs. 28 and 29.

The differences in performance was ascribed to differences of magnetic fields acting on the arc.

To demonstrate the effect of the magnetic field, various arrangements of connections of brush rigging were made, each to produce a different field where the arcing occurs. The results indicate that it is possible to arrange the brush rigging and connection to make a barrier, as described above, effective on practically all commutating machines and to prevent complete flashover. Figs. 30 and 31 show the effects of change in connection on arc distribution, giving the uniform distribution most favorable to good barrier performance.

Other tests were made to record the simultaneous short circuit current in the outer, middle and inner brushes by the oscillograph. The records in Figs. 32, 33 and 34 show typical variations of current distribution produced by different connections to brushes. The distribution of current is principally dependent on the magnetic field surrounding the brushes where the arc is formed. To show that differences of impedance have very little influence, record Fig. 35 was taken with current supplied from an exterior source with no flashing. It will be seen that current is practically the same in all brushes. With some connections the deflection of the arc can be plainly seen to follow the well-known relation, as given in Fig. 36, but with the more complicated connections the difficulty of determining resultant field from many sources makes it difficult to determine the direction of deflection of the arc except by experiment.

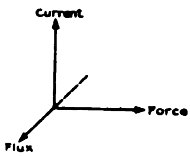


FIG. 36

Direct-current machines for use in * automatic substations are being equipped with these barriers and short-circuit tests at the substations have been taken, indicating that they will take care of any short circuit experienced in actual service. These barriers are in operation and short-circuit tests were taken on a 500-kilowatt, 600-volt, 25-cycle synchronous converter of the Des Moines Electric Railway, Des Moines, Iowa, a 500 kilowatt, 600-volt, 60-cycle synchronous converter of the Coumbus Electric Railway & Light Company, Columbus, Ohio, and a 500-kilowatt,

30-cycle, 1200-volt synchronous converter at Montieth Junction, Michigan, and other installations are now in service.

The investigations and tests indicate that if any commutating machine is equipped with barriers and the last high-speed circuit breaker described, complete protection will be given against external short circuits of all kinds so that interruption to service will not be of any greater duration than necessary for closing the circuit breaker as in ordinary overload operation.

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*See paper by Taylor and Allen, A.I.E.E. TRANSACTIONS Vol. 34, 1915, page 1801.

To be presented at the 34th Annual Convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 28, 1918.

METHOD OF SYMMETRICAL CO-ORDINATES APPLIED TO THE SOLUTION OF POLYPHASE NETWORKS

BY C. L. FORTESCUE

ABSTRACT OF PAPER

In the introduction a general discussion of unsymmetrical systems of co-planar vectors leads to the conclusion that they may be represented by symmetrical systems of the same number of vectors, the number of symmetrical systems required to define the given system being equal to its degrees of freedom. A few trigonometrical theorems which are to be used in the paper are called to mind. The paper is subdivided into three parts, an abstract of which follows. It is recommended that only that part of Part I up to formula (33) and the portion dealing with star-delta transformations be read before proceeding with Part II.

Part I deals with the resolution of unsymmetrical groups of numbers into symmetrical groups. These numbers may represent rotating vectors of systems of operators. A new operator termed the sequence operator is introduced which simplifies the manipulation. Formulas are derived for three-phase circuits. Star-delta transformations for symmetrical co-ordinates are given and expressions for power deduced. A short discussion of harmonics in three-phase systems is given.

Part II deals with the practical application of this method to symmetrical rotating machines operating on unsymmetrical circuits. General formulas are derived and such special cases, as the single-phase induction motor, synchronous motor-generator, phase converters of various types, are discussed.

INTRODUCTION

IN THE latter part of 1913 the writer had occasion to investigate mathematically the operation of induction motors under unbalanced conditions. The work was first carried out, having particularly in mind the determination of the operating characteristics of phase converters which may be considered as a particular case of unbalanced motor operation, but the scope of the subject broadened out very quickly and the writer undertook this paper in the belief that the subject would be of interest to many.

The most striking thing about the results obtained was their

Manuscript of this paper was received April 24, 1918.

symmetry; the solution always reduced to the sum of two or more symmetrical solutions. The writer was then led to inquire if there were no general principles by which the solution of unbalanced polyphase systems could be reduced to the solution of two or more balanced cases. The present paper is an endeavor to present a general method of solving polyphase network which has peculiar advantages when applied to the type of polyphase networks which include rotating machines.

In physical investigations success depends often on a happy choice of co-ordinates. An electrical network being a dynamic system should also be aided by the selection of a suitable system of co-ord nates. The co-ordinates of a system are quantities which when given, completely define the system. Thus a system of three co-planar congruent vectors are defined when their magnitude and their angular position with respect to some fixed direction are given. Such a system may be said to have six degrees of freedom, for each vector may vary in magnitude and phase position without regard to the others. If, however, we impose the condition that the vector sum of these vectors shall be zero, we find that with the direction of one vector given, the other two vectors are completely defined when their magnitude alone is given, the system has therefore lost two degrees of freedom by imposing the above condition which in dynamical theory is termed a "constraint". If we impose a further condition that the vectors be symmetrically disposed about their common origin this system will now have but two degrees of freedom.

It is evident from the above definition that a system of n coplanar congruent vectors may have $2n$ degrees of freedom and that a system of n symmetrically spaced vectors of equal magnitude has but two degrees of freedom. It should be possible then by a simple transformation to define the system of n arbitrary congruent vectors by n other systems of congruent vectors wh ch are symmetrical and have a common point. The n symmetr cal systems so obtained are the symmetrical co-ordinates of the given system of vectors and completely define it.

This method of representing polyphase systems has been employed in the past to a limited extent, but up to the present time there has been as far as the author is aware no systematic presentation of the method. The writer hopes by this paper to interest others in the application of the method, which will be

found to be a valuable instrument for the solution of certain classes of polyphase networks.

In dealing with alternating currents in this paper, use is made of the complex variable which in its most general form may be represented as a vector of variable length rotating about a given point at variable angular velocity or better as the resultant of a number of vectors each of constant length rotating at different angular velocities in the same direction about a given point. This vector is represented in the text by $\check{I}$, $\check{E}$, etc., and the conjugate vector which rotates at the same speed in the opposite direction is represented by $\hat{I}$, $\hat{E}$, etc. The effective value of the vector is represented by the symbol without the distinguishing mark as I, E, etc. The impedances Z_a, Z_b, Z_{ab}, etc., are generally functions of the operator, $D = \dfrac{d}{dt}$ and the characteristics of the circuit; these characteristics are constants only when there is no physical motion. It will therefore be necessary to carefully distinguish between $Z_a \, \check{I}_a$ and $\check{I}_a \, Z_a$ when Z_a has the form of a differential operator. In the first case a differential operation is carried out on the time variable $\check{I}_a$ in the second case the differential operator is merely multiplied by $\check{I}_a$.

The most general expression for a simple harmonic quantity e is

$$e = A \cos pt - B \sin pt$$

in exponential form this becomes

$$e = \frac{A + j\,B}{2}\, e^{j\,pt} + \frac{A - j\,B}{2}\, e^{-j\,pt} \quad .$$

$(A + j\,B)\, e^{j\,pt}$ represents a vector of length $\sqrt{A^2 + B^2}$ rotating in the positive direction with angular velocity p while $(A - j\,B)$ $e^{-j\,pt}$ is the conjugate vector rotating at the same angular velocity in the opposite direction. Since $e^{j\,pt}$ is equal to $\cos pt + j \sin pt$, the positively rotating vector $\check{E} = (A + j\,B)\, e^{j\,pt}$ will be

$$\check{E} = A \cos pt - B \sin pt + j\,(A \sin pt + B \cos pt)$$

or the real part of $\check{E}$ which is its projection on a given axis is equal to e and therefore $\check{E}$ may be taken to represent e in phase and magnitude. It should be noted that the conjugate vector $\hat{E}$ is equally available, but it is not so convenient since the

operation $\frac{d}{dt}\,e^{-jpt}$ gives $-j\,p\,e^{-jpt}$ and the imaginary part of the impedance operator will have a negative sign.

The complex roots of unity will be referred to from time to time in the paper. Thus the complete solution of the equation $x^n - 1 = 0$ requires n different values of x, only one of which is real when n is an odd integer. To obtain the other roots we have the relation

$$\begin{aligned} 1 &= \cos 2\,\pi\,r + j \sin 2\,\pi\,r \\ &= e^{j\,2\,\pi\,r} \end{aligned}$$

Where r is any integer. We have therefore

$$1^{\frac{1}{n}} = e^{j\frac{2\,\pi\,r}{n}}$$

and by giving successive integral values to r from 1 to n, all the n roots of $X^n - 1 = 0$ are obtained namely,

$$\begin{aligned} a_1 &= e^{j\frac{2\,\pi}{n}} = \cos \frac{2\,\pi}{n} + j \sin \frac{2\,\pi}{n} \\ a_2 &= e^{j\frac{4\,\pi}{n}}\ \cos \frac{4\,\pi}{n} + j \sin \frac{4\,\pi}{n} \\ a_3 &= e^{j\frac{6\,\pi}{n}}\ \cos \frac{6\,\pi}{n} + j \sin \frac{6\,\pi}{n} \\ a_n &= e^{j\,2\,\pi} = 1 \end{aligned}$$

It will be observed that $a_2\ a_3 \ldots . a_n$ are respectively equal to $a_1^2\ a_1^3 \ldots . a_1^{(n-1)}$.

When there is relative motion between the different parts of a circuit as for example in rotating machinery, the mutual inductances enter into the equation as time variables and when the motion is angular the quantities $e^{j w t}$ and $e^{-j w t}$ will appear in the operators. In this case we do not reject the portion of the operator having $e^{-j w t}$ as a factor, because the equations require that each vector shall be operated on by the operator as a whole which when it takes the form of a harmonic time function will contain terms with $e^{j w t}$ and $e^{-j w t}$ in conjugate relation. In some cases as a result of this, solutions will appear with indices of e which are negative time variables; in such cases the vectors with negative index should be replaced by their conjugates which rotate in the positive direction.

This paper is subdivided as follows:

Part I.—"The Method of Symmetrical Co-ordinates." Deals with the theory of the method, and its application to simple polyphase circuits.

Part II.—Application to Symmetrical Machines on Unbalanced Polyphase Circuits. Takes up Induction Motors, Generator and Synchronous Motor, Phase Balancers and Phase Convertors.

Part III. Application to Machines having Unsymmetrical Windings.

In the Appendix the mathematical representation of field forms and the derivation of the constants of different forms of networks is taken up.

The portions of Part I dealing with unsymmetrical windings are not required for the applications taken up in Part II and may be deferred in a later reading. The greater part of Part I is taken up in deriving formulas for special cases from the general formulae (**30**) and (**33**), and the reading of the text following these equations may be confined to the special cases of immediate interest.

I wish to express my appreciation of the valuable help and suggestions that have been given me in the preparation of this paper by Prof. Karapetoff who suggested that the subject be presented in a mathematical paper and by Dr. J. Slepian to whom I am indebted for the idea of sequence operators and by others who have been interested in the paper.

PART I

Method of Symmetrical Generalized Co-ordinates

Resolution of Unbalanced Systems of Vectors and Operators

The complex time function $\check{E}$ may be used instead of the harmonic time function e in any equation algebraic or differential in which it appears linearly. The reason of this is because if any linear operation is performed on $\check{E}$ the same operation performed on its conjugate $\hat{E}$ will give a result which is conjugate to that obtained from $\check{E}$, and the sum of the two results obtained is a solution of the same operation performed on $\check{E} + \hat{E}$, or $2\,e$.

It is customary to interpret $\check{E}$ and $\hat{E}$ as coplanar vectors, rotating about a common point and e as the projection of either vector on a given line, $\check{E}$ being a positively rotating vector and

$\hat{E}$ being a negatively rotating vector, and their projection on the given line being

$$e = \frac{\check{E} + \hat{E}}{2} \tag{1}$$

Obviously if this interpretation is accepted one of the two vectors becomes superfluous and the positively rotating vector $\check{E}$ may be taken to represent the variable "e" and we may define "e" by saying that "e" is the projection of the vector $\check{E}$ on a given line or else by saying that "e" is the real part of the complex variable $\check{E}$.

If $1, a, a^2 \ldots a^{n-1}$ are the n roots of the equation $x^n - 1 = 0$ a symmetrical polyphase system of n phases may be represented by

$$\left.\begin{aligned} \check{E}_{11} &= \check{E}_{11} \\ \check{E}_{21} &= a\,\check{E}_{11} \\ \check{E}_{31} &= a^2\,\check{E}_{11} \\ &\ldots\ldots\ldots\ldots \\ &\ldots\ldots\ldots\ldots \\ \check{E}_{n1} &= a^{n-1}\,\check{E}_{11} \end{aligned}\right\} \tag{2}$$

Another n phase system may be obtained by taking

$$\left.\begin{aligned} \check{E}_{12} &= \check{E}_{12} \\ \check{E}_{22} &= a^2\,\check{E}_{12} \\ \check{E}_{32} &= a^4\,\check{E}_{12} \\ &\ldots\ldots\ldots\ldots \\ &\ldots\ldots\ldots\ldots \\ \check{E}_{n2} &= a^{2(n-1)}\check{E}_{12} \end{aligned}\right\} \tag{3}$$

and this also is symmetrical, although it is entirely different from (**2**).

Since $1 + a + a^2 + a^{n-1} = 0$, the sum of all the vectors of a symmetrical polyphase system is zero.

If $\check{E}_1\ \check{E}_2\ \check{E}_3 \ldots \check{E}_n$ be a system of n vectors, the following identities may be proved by inspection:

$$
\left.
\begin{aligned}
\check{E}_1 \equiv{}& \frac{\check{E}_1 + \check{E}_2 + \check{E}_3 + \ldots . \check{E}_n}{n}\\
&+ \frac{\check{E}_1 + a\,\check{E}_2 + a^2\,\check{E}_3 + \ldots . a^{n-1}\,\check{E}_n}{n}\\
&+ \frac{\check{E}_1 + a^2\,\check{E}_2 + a^4\check{E}_3 + \ldots . a^{2(n-1)}\,\check{E}_n}{n}\\
&+ \frac{\check{E}_1 + a^{r-1}\,\check{E}_2 + a^{2(r-1)}\,\check{E}_3 + \ldots . a^{(n-1)(r-1)}\,\check{E}_n}{n}\\
&+ \ldots . \frac{\check{E}_1 + a^{-1}\,\check{E}_2 + a^{-2}\,\check{E}_3 + \ldots . a^{-(n-1)}\,\check{E}_n}{n}\\
\check{E}_2 \equiv{}& \frac{\check{E}_1 + \check{E}_2 + \check{E}_3 + \ldots . \check{E}_n}{n}\\
&+ a^{-1}\,\frac{\check{E}_1 + a\,\check{E}_2 + a^2\,\check{E}_3 + \ldots . a^{n-1}\,\check{E}_n}{n}\\
&+ a^{-2}\,\frac{\check{E}_1 + a^2\,\check{E}_2 + a^4\,\check{E}_3 + \ldots . a^{2(n-1)}\,\check{E}_n}{n}\\
&+ a^{-(r-1)}\,\frac{\check{E}_1 + a^{r-1}\,\check{E}_2 + a^{2(r-1)}\,\check{E}_3 + a^{(n-1)(r-1)}\,\check{E}_n}{n}\\
&+ a^{-(n-1)}\,\frac{\check{E}_1 + a^{-1}\,\check{E}_2 + a^{-2}\,\check{E}_3 + \ldots . a^{-(n-1)}\,\check{E}_n}{n}\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\\
\check{E}_n \equiv{}& \frac{\check{E}_1 + \check{E}_2 + \check{E}_3 + \ldots . \check{E}_n}{n}\\
&+ a^{-(n-1)}\,\frac{\check{E}_1 + a\,\check{E}_2 + a^2\,\check{E}_3 + \ldots . a^{n-1}\,\check{E}_n}{n}\\
&+ a^{-2(n-1)}\,\frac{\check{E}_1 + a^2\,\check{E}_2 + a^4\,\check{E}_4 + \ldots . a^{2(n-1)}\,\check{E}_n}{n}\\
&+ a^{-(n-1)(r-1)}\,\frac{\check{E}_1 + a^{r-1}\,\check{E}_2 + \ldots . a^{(n-1)(r-1)}\,\check{E}_n}{n}\\
&+ a^{-1}\,\frac{\check{E}_1 + a^{-1}\,\check{E}_2 + a^{-2}\,\check{E}_3 + \ldots . a^{-(n-1)}\,\check{E}_n}{n}
\end{aligned}
\right\} \quad (4)
$$

It will be noted that in the expression for $\check{E}_1$ in the above formulae if the first term of each component is taken the result is

$n\,\dfrac{\check{E}_1}{n}$ or $\check{E}_1$. If the succeeding terms of each component involving $\check{E}_2\,\check{E}_3 \ldots \check{E}_n$ respectively, are taken separately they add up to expressions of the form $\dfrac{\check{E}_r}{n}\,(1+a+a^2+\ldots a^{n-1})$ which are all equal to zero since $(1+a+a^2+\ldots a^{n-1})$ is equal to zero. In like manner in the expression for $\check{E}_2\,\check{E}_3 \ldots \check{E}_n$ respectively, all the terms of the components involving each of the quantities $\check{E}_1\,\check{E}_2\,\check{E}_3 \ldots$ etc. excepting the terms involving that one of which the components are to be determined add up to expressions of the form $\dfrac{\check{E}_r}{n}$ $(1+a+a^2+\ldots a^{n-1})$ all of which are equal to zero, the remaining terms add up to $\check{E}_2\,\check{E}_3 \ldots E_n$ respectively. It will now be apparent that (**4**), is true whatever may be the nature of $\check{E}_1\,\check{E}_2$ etc., and therefore it is true of all numbers, real complex or imaginary, whatever they may represent and therefore similar relations may be obtained for current vectors and they may be extended to include not only vectors but also the operators.

In order to simplify the expressions which become unwieldy when applied to the general n phase system, let us consider a three phase system of vectors $\check{E}_a\,\check{E}_b\,\check{E}_c$. Then we have the following identities:

$$\left.\begin{aligned}
\check{E}_a &\equiv \frac{\check{E}_a+\check{E}_b+\check{E}_c}{3}+\frac{E_a+a\,\check{E}_b+a^2\,E_c}{3} \\
&\qquad +\frac{\check{E}_a+a^2\,\check{E}_b+a\,\check{E}_c}{3} \\
\check{E}_b &\equiv \frac{\check{E}_a+\check{E}_b+\check{E}_c}{3}+a^2\,\frac{\check{E}_a+a\,\check{E}_b+a^2\,E_c}{3} \\
&\qquad +a\,\frac{\check{E}_a+a^2\,\check{E}_b+a\,\check{E}_c}{3} \\
\check{E}_c &\equiv \frac{\check{E}_a+\check{E}_b+\check{E}_c}{3}+a\,\frac{\check{E}_a+a\,\check{E}_b+a^2\,\check{E}_c}{3} \\
&\qquad +a^2\,\frac{\check{E}_a+a^2\,\check{E}_b+a\,\check{E}_c}{3}
\end{aligned}\right\} \quad (5)$$

(**4**) states the law that a system of n vectors or quantities may be resolved when n is prime into n different symmetrical

groups or systems, one of which consists of n equal vectors and the remaining $(n - 1)$ systems consist of n equispaced vectors which with the first mentioned groups of equal vectors forms an equal number of symmetrical n-phase systems. When n is not prime some of the n-phase systems degenerate into repetitions of systems having numbers of phases corresponding to the factors of n.

Equation (5) states that any three vectors $\check{E}_a$ $\check{E}_b$ $\check{E}_c$ may be

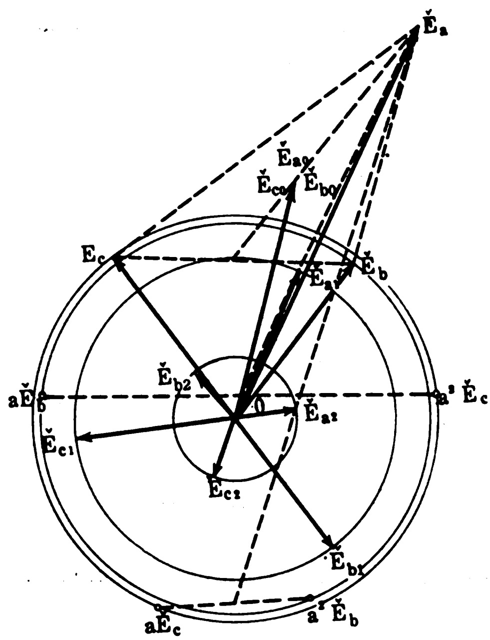

Fig. 1—Graphical Representation of Equation 5.

resolved into a system of three equal vectors $\check{E}_{a0}$ $\check{E}_{a0}$ $\check{E}_{a0}$ and two symmetrical three phase systems $\check{E}_{a1}$, $a^2\,\check{E}_{a1}$, $a\,\check{E}_{a1}$, $\check{E}_{a2}$, $a\,\check{E}_{a2}$, $a^2\,\check{E}_{a2}$, the first of which is of positive phase sequence and the second of negative phase sequence, or

$$\left.\begin{aligned} \check{E}_a &= \check{E}_{a0} + \check{E}_{a1} + \check{E}_{a2} \\ \check{E}_b &= \check{E}_{a0} + a^2\,\check{E}_{a1} + a\,\check{E}_{a2} \\ \check{E}_c &= \check{E}_{a0} + a\,\check{E}_{a1} + a^2\,\check{E}_{a2} \end{aligned}\right\} \qquad (6)$$

Similarly

$$\left.\begin{aligned} \check{I}_a &= \check{I}_{a0} + \check{I}_{a1} + \check{I}_{a2} \\ \check{I}_b &= \check{I}_{a0} + a_2\, \check{I}_{a1} + a\, \check{I}_{a2} \\ \check{I}_c &= \check{I}_{a0} + a\, \check{I}_{a1} + a^2\, \check{I}_{a2} \end{aligned}\right\} \tag{7}$$

Figs. (1) and (2) show a graphical method of resolving three vectors into their symmetrical three-phase components corresponding to equations (5).

The system of operators $Z_{aa}\ Z_{bb}\ Z_{cc}\ Z_{ab}\ Z_{bc}\ Z_{ca}$ may be resolved in a similar manner into symmetrical groups,

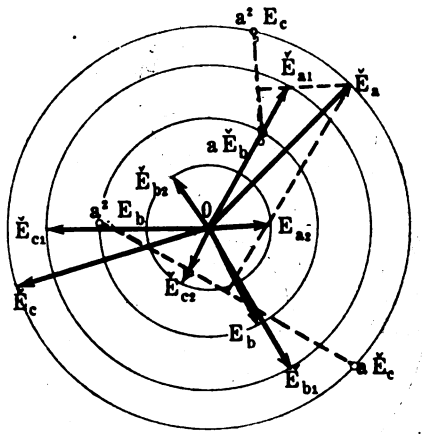

Fig. 2—Graphical Representation of Equation 5.

$$\left.\begin{aligned} Z_{aa} &= Z_{aa0} + Z_{aa1} + Z_{aa2} \\ Z_{bb} &= Z_{aa0} + a^2\, Z_{aa1} + a\, Z_{aa2} \\ Z_{cc} &= Z_{aa0} + a\, Z_{aa1} + a^2\, Z_{aa2} \end{aligned}\right\} \tag{8}$$

$$\left.\begin{aligned} Z_{ab} &= Z_{ab0} + Z_{ab1} + Z_{ab2} \\ Z_{bc} &= Z_{ab0} + a^2\, Z_{ab1} + a\, Z_{ab2} \\ Z_{ca} &= Z_{ab0} + a\, Z_{ab1} + a^2\, Z_{ab2} \end{aligned}\right\} \tag{9}$$

There are similar relations for n phase systems.

EXPLANATION OF THEORY AND USE OF SEQUENCE OPERATOR

Consider the following sequences of nth roots of unity:

$$\left.\begin{aligned}
S^0 &= 1,\quad 1,\quad 1 \ldots . 1\\
S^1 &= 1,\quad a^{-1},\quad a^{-2} \ldots . a^{-(n-1)}\\
S^2 &= 1,\quad a^{-2},\quad a^{-4} \ldots . a^{-2(n-1)}\\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\\
S^r &= 1,\quad a^{-r},\quad a^{-2r} \ldots . a^{-(n-1)r}\\
S^{r+1} &= 1,\quad a^{-(r+1)},\quad a^{-2(r+1)} \ldots . a^{-(n-1)(r+1)}\\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\\
S^{n-1} &= 1,\quad a^{-(n-1)},\quad a^{-2(n-1)} \ldots . a^{-(n-1)^2}
\end{aligned}\right\} \qquad (10)$$

Consider the sequence obtained by the products of similar terms of S^r and S^1. It will be

$$S^{r+1} = 1,\quad a^{-(r+1)},\quad a^{-2(r+1)} \ldots . a^{-(n-1)(r+1)} \qquad (11)$$

Similarly

$$S^k = 1,\quad a^{-k},\quad a^{-2k} \ldots . a^{-(n-1)k} \qquad (12)$$

and the sequence obtained by products of like terms of this sequence and S^r is

$$S^{r+k} = 1,\quad a^{-(r+k)},\quad a^{-2(r+k)} \ldots . a^{-(n-1)(r+k)} \qquad (13)$$

We may therefore apply the law of indices to the products of sequences to obtain the resulting sequence.

In the case of the three-phase system we shall have the following sequences only to consider, viz.:

$$\left.\begin{aligned}
S^0 &= 1,\quad 1,\quad 1\\
S^1 &= 1,\quad a^2,\quad a\\
S^2 &= 1,\quad a,\quad a^2
\end{aligned}\right\} \qquad (14)$$

The complete system of currents $\dot{I}_a$ $\dot{I}_b$ $\dot{I}_c$ are defined by

$$S(\dot{I}_a) = S^0 \dot{I}_{a0} + S^1 \dot{I}_{a1} + S^2 \dot{I}_{a2} \qquad (15)$$

Similarly the impedances Z_{aa} Z_{bb} Z_{cc} may be expressed in symmetrical form

$$S(Z_{aa}) \equiv S^0 Z_{aa0} + S^1 Z_{aa1} + S^2 Z_{aa2} \qquad (16)$$

and the mutual impedances Z_{ab}, Z_{bc}, Z_{ca} are expressed by

$$S(Z_{ab}) \equiv S^0 Z_{ab0} + S^1 Z_{ab1} + S^2 Z_{ab2} \qquad (17)$$

Attention is called to the importance of preserving the cyclic order of self and mutual impedances, otherwise the rule for the sequence operator will not hold. Thus, Z_{ab}, Z_{bc} and Z_{ca} are in proper sequence as also are Z_{ca}, Z_{ab}, Z_{bc}.

When it is desired to change the first term in the sequence of polyphase vectors the resulting expression will be

$$\left.\begin{aligned} S(\check{I}_b) &= S^0\, \check{I}_{a0} + S^1\, a^2\, \check{I}_{a1} + S^2\, a\, \check{I}_{a2} \\ S(\check{I}_c) &= S^0\, \check{I}_{a0} + S^1\, a\, \check{I}_{a1} + S^2\, a^2\, \check{I}_{a2} \end{aligned}\right\} \qquad \textbf{(18)}$$

Similarly in the case of the operators $S\,(Z_{ab})$ we have

$$\left.\begin{aligned} S(Z_{bc}) &= S^0\, Z_{ab0} + S^1\, a^2\, Z_{ab1} + S^2\, a\, Z_{ab2} \\ S(Z_{ca}) &= S^0\, Z_{ab0} + S^1\, a\, Z_{ab1} + S^2\, a^2\, Z_{ab2} \end{aligned}\right\} \qquad \textbf{(19)}$$

Similar rules apply to the e.m.fs. $E_a\ E_b\ E_c$

$$\left.\begin{aligned} S(\check{E}_a) &= S^0\, \check{E}_{a0} + S^1\, \check{E}_{a1} + S^2\, \check{E}_{a2} \\ S(\check{E}_b) &= S^0\, \check{E}_{a0} + S^1\, a^2\, \check{E}_{a1} + S^2\, a\, \check{E}_{a2} \\ S(\check{E}_c) &= S^0\, \check{E}_{a0} + S^1\, a\, E_{a1} + S^2\, a^2\, \check{E}_{a2} \end{aligned}\right\} \qquad \textbf{(20)}$$

It should be kept in mind that any one of the several expressions $S\,(\check{I}_a)$ $S\,(\check{I}_b)$ $S\,(\check{I}_c)$, etc., completely specifies the system, and each of the members of the groups of equations given above is a complete statement of the system of vectors or operators and their relation.

Application to Self and Mutual Impedance Operations

We may now proceed with the current, systems $S\,(\check{I}_a)$, $S\,(\check{I}_b)$, $S\,(\check{I}_c)$ and the operating groups $S\,(Z_{aa})$ $S\,(Z_{bb})$ $S\,(Z_{cc})$ etc. and the electromotive forces in exactly the same manner as for simple a-c. circuits. Thus,

$$\begin{aligned} S(\check{E}_a) &= S(Z_{aa})\, S(\check{I}_a) + S(Z_{ab})\, S(\check{I}_b) + S(Z_{ca})\, S(\check{I}_c) \qquad \textbf{(21)} \\ &= (S^0\, Z_{aa0} + S^1\, Z_{aa1} + S^2\, Z_{aa2})\,(S^0\, \check{I}_{a0} + S^1\, \check{I}_{a1} + S^2\, I_{a2}) \\ &\quad + (S^0\, Z_{ab0} + S^1\, Z_{ab1} + S^2\, Z_{ab2}) \\ &\qquad\qquad (S^0\, \check{I}_{a0} + S^1\, a^2\, \check{I}_a + S^2\, a\, \check{I}_{a2}) \\ &\quad + (S^0\, Z_{ab0} + S^1\, a\, Z_{ab1} + S^2\, a^2\, Z_{ab2}) \\ &\qquad\qquad (S^0\, \check{I}_{a0} + S^1\, a\, \check{I}_{a1} + S^2\, a^2\, \check{I}_{a2}) \\ &= S^0\,(Z_{aa0} + 2\, Z_{ab0})\, \check{I}_{a0} + S^0\,\{Z_{aa2} + (1 + a^2)\, Z_{ab2}\}\, \check{I}_{a1} \end{aligned}$$

$$
\begin{aligned}
&+ S^0 \{Z_{aa1} + (1 + a)\, Z_{ab1}\}\, \check{I}_{a2} \\
&+ S^1 \{Z_{aa1} + (1 + a)\, Z_{ab1}\}\, \check{I}_{a0} \\
&+ S^1 \{Z_{aa0} + (a + a^2)\, Z_{ab0}\}\, \check{I}_{a1} \\
&+ S^1 \{Z_{aa2} + 2\, a\, Z_{ab2}\}\, \check{I}_{a2} \\
&+ S^2 \{Z_{aa2} + (1 + a^2)\, Z_{ab2}\}\, \check{I}_{a0} \\
&+ S^2 \{Z_{aa1} + 2\, a^2\, Z_{ab1}\}\, \check{I}_{a1} \\
&+ S^2 \{Z_{aa0} + (a + a^2)\, Z_{ab0}\}\, \check{I}_{a2}
\end{aligned} \tag{22}
$$

Or since $1 + a + a^2 = 0$, $1 + a = -a^2$, $1 + a^2 = -a$ and $a + a^2 = -1$

$$
\begin{aligned}
S(\check{E}_a) = {} & S^0 (Z_{aa0} + 2\, Z_{ab0})\, \check{I}_{a0} + S^0 (Z_{aa2} - a\, Z_{ab2})\, \check{I}_{a1} \\
&+ S^0 (Z_{aa1} - a^2\, Z_{ab1})\, \check{I}_{a2} + S^1 (Z_{aa1} - a^2\, Z_{ab1})\, \check{I}_{a0} \\
&+ S^1 (Z_{aa0} - Z_{ab0})\, \check{I}_{a1} + S^1 (Z_{aa2} + 2\, a\, Z_{ab2})\, \check{I}_{a2} \\
&+ S^2 (Z_{aa2} - a\, Z_{ab2})\, \check{I}_{a0} + S^2 (Z_{aa1} + 2\, a^2\, Z_{ab1})\, \check{I}_{a1} \\
&+ S^2 (Z_{aa0} - Z_{ab0})\, \check{I}_{a2}
\end{aligned} \tag{23}
$$

Or since

$$
\begin{aligned}
S(Z_{bc}) &= S^0\, Z_{bc0} + S^1\, Z_{bc1} + S^2\, Z_{bc2} \\
&= S^0\, Z_{ab0} + S^1\, a^2\, Z_{ab1} + S^2\, a\, Z_{ab2}
\end{aligned}
$$

we may write (**23**) in the form

$$
\begin{aligned}
S(\check{E}_a) = {} & S^0 (Z_{aa0} + 2\, Z_{bc0})\, \check{I}_{a0} + S^0 (Z_{aa2} - Z_{bc2})\, \check{I}_{a1} \\
&+ S^0 (Z_{aa1} - Z_{bc1})\, \check{I}_{a2} + S^1 (Z_{aa1} - Z_{bc1})\, \check{I}_{a0} \\
&+ S^1 (Z_{aa0} - Z_{bc0})\, \check{I}_{a1} + S^1 (Z_{aa2} + 2\, Z_{bc2})\, \check{I}_{a2} \\
&+ S^2 (Z_{aa2} - Z_{bc2})\, \check{I}_{a0} + S^2 (Z_{aa1} + 2\, Z_{bc1})\, \check{I}_{a1} \\
&+ S^2 (Z_{aa0} - Z_{bc0})\, \check{I}_{a2}
\end{aligned} \tag{24}
$$

which is the more symmetrical form. We have therefore from (**24**) by expressing $S(\check{E}_a)$ in terms of symmetrical co-ordinates the three symmetrical equations

$$
\left.
\begin{aligned}
S^0\, \check{E}_{a0} &= S^0 \{(Z_{aa0} + 2\, Z_{bc0})\, \check{I}_{a0} + (Z_{aa2} - Z_{bc2})\, \check{I}_{a1} \\
&\qquad + (Z_{aa1} - Z_{bc1})\, \check{I}_{a2}\} \\
S^1\, E_{a1} &= S^1 \{(Z_{aa1} - Z_{bc1})\, \check{I}_{a0} + (Z_{aa0} - Z_{bc0})\, \check{I}_{a1} \\
&\qquad + (Z_{aa2} + 2\, Z_{bc2})\, \check{I}_{a2}\} \\
S^2\, E_{a2} &= S^2 \{(Z_{aa2} - Z_{bc2})\, \check{I}_{a0} + (Z_{aa1} + 2\, Z_{bc1})\, \check{I}_{a1} \\
&\qquad + (Z_{aa0} - Z_{bc0})\, \check{I}_{a2}\}
\end{aligned}
\right\} \tag{25}
$$

An important case to which we must next give consideration is that of mutual inductance between a primary polyphase circuit and a secondary polyphase circuit. The mutual impedances may be arranged in three sets. Let the currents in the secondary windings be I_u I_v and I_w, we may then express the generalized mutual impedances as follows:

$$\left.\begin{array}{r}\text{(I) } Z_{au}\ Z_{bv}\ Z_{cw} \\ \text{(II) } Z_{bw}\ Z_{cu}\ Z_{av} \\ \text{(III) } Z_{cv}\ Z_{aw}\ Z_{bu}\end{array}\right\} \qquad (26)$$

Each set may be resolved into three symmetrical groups, so that

$$\left.\begin{array}{l} S\,(Z_{au}) = S^0\, Z_{au0} + S^1\, Z_{au1} + S^2\, Z_{au2} \\ S\,(Z_{bw}) = S^0\, Z_{bw0} + S^1\, Z_{bw1} + S^2\, Z_{bw2} \\ S\,(Z_{cv}) = S^0\, Z_{cv0} + S^1\, Z_{cv1} + S^2\, Z_{cv2} \end{array}\right\} \qquad (27)$$

and we have for $S\,(\check{E}_a)$ the primary induced e.m.f. due to the secondary currents $S\,(\check{I}_u)$

$$S\,(\check{E}_a) = S\,(Z_{au})\, S\,(\check{I}_u) + S\,(Z_{av})\, S\,(\check{I}_v) + S\,(Z_{aw})\, S\,(\check{I}_w) \qquad (28)$$

Substituting for $S\,(\check{I}_u)$, $S\,(\check{I}_v)$ and $S\,(\check{I}_w)$ and $S\,(Z_{au})$, $S\,(Z_{av})$, $S\,(Z_{aw})$ their symmetrical equivalents we have

$$\begin{aligned} S\,(\check{E}_a) = {} & S^0\,(Z_{au0} + Z_{bw0} + Z_{cv0})\, I_{uo} \\ & + S^0\,(Z_{au2} + a\, Z_{bw2} + a^2\, Z_{cv2})\, \check{I}_{u1} \\ & + S^0\,(Z_{au1} + a^2\, Z_{bw1} + a\, Z_{cv1})\, \check{I}_{u2} \\ & + S^1\,(Z_{au1} + a\, Z_{bw1} + a^2\, Z_{cv1})\, \check{I}_{u0} \\ & + S^1\,(Z_{au0} + a^2\, Z_{bw0} + a\, Z_{cv0})\, \check{I}_{u1} \\ & + S^1\,(Z_{au2} + Z_{bw2} + Z_{cv2})\, \check{I}_{u2} \\ & + S^2\,(Z_{au2} + a^2\, Z_{bw2} + a\, Z_{v2})\, \check{I}_{u0} \\ & + S^2\,(Z_{au1} + Z_{bw1} + Z_{cv1})\, \check{I}_{u1} \\ & + S^2\,(Z_{au0} + a\, Z_{bw0} + a^2\, Z_{cv0})\, \check{I}_{u2} \end{aligned} \qquad (29)$$

On expressing $S\ (\check{E}_a)$ in symmetrical form we have the following three symmetrical equations

$$\left.\begin{aligned} S^0\ \check{E}_{a0} = S^0\ \{&(Z_{au0} + Z_{bw0} + Z_{cv0})\ \check{I}_{u0} \\ &+ (Z_{au2} + a\ Z_{bw2} + a^2\ Z_{cv2})\ \check{I}_{u1} \\ &+ (Z_{au1} + a^2\ Z_{bw1} + a\ Z_{cv1})\ \check{I}_{u2}\} \\ S^1\ \check{E}_{a1} = S^1\ \{&(Z_{au1} + a\ Z_{bw1} + a^2\ Z_{cv1})\ \check{I}_{u0} \\ &+ (Z_{au0} + a^2\ Z_{bw0} + a\ Z_{cv0})\ \check{I}_{u1} \\ &+ (Z_{au2} + Z_{bw2} + Z_{cv2})\ \check{I}_{u2}\} \\ S^2\ E_{a2} = S^2\ \{&(Z_{au2} + a^2\ Z_{bw2} + a\ Z_{cv2})\ \check{I}_u{}^0 \\ &+ (Z_{au1} + Z_{bw1} + Z_{cv1})\ \check{I}_{u1} \\ &+ (Z_{au0} + a\ Z_{bw0} + a^2\ Z_{cv0})\ \check{I}_{u2}\} \end{aligned}\right\} \qquad (30)$$

For the e.m.f. $S\ (\check{E}_u)$ induced in the secondary by the primary currents $S\ (\check{I}_a)$ we have

$$S\ (\check{E}_u) = S\ (Z_{au})\ S\ (\check{I}_a) + S\ (Z_{bu})\ S\ (\check{I}_b) + S\ (Z_{cu})\ S\ (\check{I}_c) \qquad (31)$$

Since $S\ (Z_{bu})$ bears the same relation to $S\ (Z_{cv})$ as $S\ (Z_{av})$ does to $S\ (Z_{bw})$ and $S\ (Z_{au})$ bears the same relation to $S\ (Z_{bw})$ as $S\ (Z_{aw})$ does to $S\ (Z_{cv})$ to obtain $S\ (\check{E}_u)$ all that will be necessary will be to interchange Z_{bw} and Z_{cv} in (**29**) and change $\check{I}_{u0}\ \check{I}_{u1}\ \check{I}_{u2}$ to $\check{I}_{a0}\ I_{a1}$ and $\check{I}_{a2}$ respectively, this gives

$$\begin{aligned} S\ (\check{E}_u) = S^0\ &(Z_{au0} + Z_{bw0} + Z_{cv0})\ \check{I}_{a0} \\ &+ S^0\ (Z_{au2} + a^2\ Z_{bw2} + a\ Z_{cv2})\ \check{I}_{a1} \\ &+ S^0\ (Z_{au1} + a\ Z_{bw1} + a^2\ Z_{cv1})\ \check{I}_{a2} \\ &+ S^1\ (Z_{au1} + a^2\ Z_{bw1} + a\ Z_{cv1})\ \check{I}_{a0} \\ &+ S^1\ (Z_{au0} + a\ Z_{bw0} + a^2\ Z_{cv0})\ \check{I}_{a1} \\ &+ S^1\ (Z_{au2} + Z_{bw2} + Z_{cv2})\ \check{I}_{a2} \\ &+ S^2\ (Z_{au2} + a\ Z_{bw2} + a^2\ Z_{cv2})\ \check{I}_{a0} \\ &+ S^2\ (Z_{au1} + Z_{bw1} + Z_{cv1})\ \check{I}_{a1} \\ &+ S^2\ (Z_{au0} + Z_{bw0} + Z_{cv0})\ \check{I}_{a2} \end{aligned} \qquad (32)$$

and the three symmetrical equations will be

$$\left.\begin{aligned}
S^0 \check{E}_{u0} = S^0 \{&(Z_{au0} + Z_{bw0} + Z_{cv0})\ \check{I}_{a0} \\
&+ (Z_{au2} + a^2 Z_{bw2} + a\, Z_{bw2} + a\, Z_{cv2})\ \check{I}_{a1} \\
&+ (Z_{au1} + a\, Z_{bw1} + a^2 Z_{cv1})\ \check{I}_{a2}\} \\
S^1 \check{E}_{a1} = S^1 \{&(Z_{au1} + a^2 Z_{bw1} + a\, Z_{cv1})\ \check{I}_{a0} \\
&+ (Z_{au0} + a\, Z_{bw0} + a^2 Z_{cv0})\ \check{I}_{a1} \\
&+ (Z_{au2} + Z_{bw2} + Z_{cv2})\ \check{I}_{a2}\} \\
S^2 \check{E}_{u2} = S^2 \{&(Z_{au2} + a\, Z_{bw2} + a^2 Z_{cr2})\ \check{I}_{a0} \\
&+ (Z_{au1} + Z_{bw1} + Z_{cv1})\ \check{I}_{a1} \\
&+ (Z_{au0} + a^2 Z_{bw0} + a\, Z_{cv0})\ \check{I}_{a2}\}
\end{aligned}\right\} \quad \textbf{(33)}$$

The same methods may be applied to polyphase systems of any number of phase. When the number of phases is not prime the system may sometimes be dealt with as a number of polyphase systems having mutual inductance between them:—For example, a nine-phase system may be treated as three three-phase systems, a twelve phase system as three four-phase or four three-phase systems. In certain froms of dissymmetry this method is of great practical value, and its application will be taken up later.

For the present part of the paper we shall confine ourselves to the three-phase system, and dissymmetries of several different kinds.

The operators Z_{au} Z_{aa}, etc., must be interpreted in the broadest sense. They may be simple complex quantities or they may be functions of the differential operator $\frac{d}{dt}$. For if

$$i = \Sigma\ (A_n \cos n\, w\, t + B_n \sin n\, w\, t)$$

it may be expressed in the form

$$\left.\begin{aligned}
i &= \Sigma \left(\frac{A_n - j\, B_n}{2}\ e^{jnwt} + \frac{A_n + j\, B_n}{2}\ e^{-jnwt}\right) \\
&= \frac{\check{I}}{2} + \frac{\hat{I}}{2} \\
&= \text{real part of } \check{I}
\end{aligned}\right\} \quad \textbf{(34)}$$

and any linear algebraic operation performed on $\check{I}/2$ will give a result which will be conjugate to that obtained by carrying out the same operation on $\hat{I}/2$ and since the true solution is the sum of these results, it may also be obtained by taking the real part of the result of performing the operation on $\check{I}$.

Modification of the General Case Met With in Practical Networks

Several symmetrical arrangements of the operator Z_{au} etc. are frequently met with in practical networks which result in a much simpler system of equations than those obtained for the general case as in equations (**29**) to (**33**). Thus for example if all the operators in (**26**) are equal, all the operators in (**27**), except $S^0\, Z_{au0}$ $S^0\, Z_{bw0}$ and $S^0\, Z_{cv0}$ are equal to zero, and these three quantities are also equal to one another so that equation (**30**) becomes

$$\left.\begin{aligned} S^0\, \check{E}_{a0} &= S^0\,(Z_{au0} + Z_{bw0} + Z_{cv0})\, \check{I}_{u0} \\ S^1\, \check{E}_{a1} &= 0 \\ S^2\, E_{a2} &= 0 \end{aligned}\right\} \qquad (\mathbf{35})$$

and equation (**33**)

$$\left.\begin{aligned} S^0\, \check{E}_{u0} &= S^0\,(Z_{au0} + Z_{bw0} + Z_{cv0})\, \check{I}_{a0} \\ S^1\, E_{u1} &= 0 \\ S^2\, E_{u2} &= 0 \end{aligned}\right\} \qquad (\mathbf{36})$$

This is the statement in symmetrical co-ordinates that a symmetrically disposed polyphase transmission line will produce no electromagnetic induction in a second similar polyphase system so disposed with respect to the first that mutual inductions between all phases of the two are equal except that due to single-phase currents passing through the conductors.

If in (**26**) the quantities in each group only are equal, equations (**30**) and (**33**) become

$$\left.\begin{aligned} S^0\, \check{E}_{a0} &= S^0\,(Z_{au0} + Z_{bw0} + Z_{cv0})\, \check{I}_{u0} \\ S^1\, \check{E}_{a1} &= S^1\,(Z_{au0} + a^2\, Z_{bw0} + a\, Z_{cv0})\, \check{I}_{u1} \\ S^2\, \check{E}_{a2} &= S^2\,(Z_{au0} + a\, Z_{bw0} + a^2\, Z_{cv0})\, \check{I}_{u2} \end{aligned}\right\} \qquad (\mathbf{37})$$

$$\left.\begin{aligned} S^0 \check{E}_{u0} &= S^0 (Z_{au0} + Z_{bw0} + Z_{cv0}) \check{I}_{a0} \\ S^1 \check{E}_{a1} &= S^1 (Z_{au0} + a\, Z_{bw0} + a^2 Z_{cv0}) \check{I}_{a1} \\ S^2 \check{E}_{a2} &= S^1 (Z_{au0} + a^2 Z_{bw0} + a\, Z_{cv0}) \check{I}_{a2} \end{aligned}\right\} \quad (38)$$

Symmetrical Forms of Common Occurrence

A symmetrical form which is of importance because it is of frequent occurrence in practical polyphase networks has the terms in group (I) equation (26) all equal and those in group (II) $\cos\frac{2\pi}{3}$ times those in group (I) and those in group (III) $\cos\frac{4\pi}{3}$ times those in group (I).

Since $\cos\frac{2\pi}{3} = \frac{a + a^2}{2} = \cos\frac{4\pi}{3}$ we have on substituting the values of the impedances in this case,

$$\left.\begin{aligned} S^0 \check{E}_{a0} &= S^0 \{Z_{au0}(1 + a + a^2)\} \check{I}_{u0} = 0 \\ S^1 \check{E}_{a1} &= S^1 1\tfrac{1}{2} Z_{au0} \check{I}_{u1} \\ S^2 E_{a2} &= S^2 1\tfrac{1}{2} Z_{au0} \check{I}_{u2} \end{aligned}\right\} \quad (39)$$

$$\left.\begin{aligned} S^0 E_{u0} &= S^0 \{Z_{au0}(1 + a + a^2)\} \check{I}_{a0} = 0 \\ S^1 \check{E}_{u1} &= S^1 1\tfrac{1}{2} Z_{au0} \check{I}_{a1} \\ S^2 \check{E}_{u2} &= S^2 1\tfrac{1}{2} Z_{au0} \check{I}_{a2} \end{aligned}\right\} \quad (40)$$

The elements in group I may be unequal but groups II and III may be obtained from group I by multiplying by $\cos\frac{4\pi}{3}$ and $\cos\frac{2\pi}{3}$ respectively.

The members of the three groups will then be related as follows, the same sequence being used as before,

$$\left.\begin{aligned} &(\mathrm{I}) \quad Z_{au}, \quad Z_{bv}, \quad Z_{cw} \\ &(\mathrm{II}) \quad \frac{a + a^2}{2} Z_{cw}, \quad \frac{a + a^2}{2} Z_{au}, \quad \frac{a + a^2}{2} Z_{bv} \\ &(\mathrm{III}) \quad \frac{a + a^2}{2} Z_{bv}, \quad \frac{a + a^2}{2} Z_{cw}, \quad \frac{a + a^2}{2} Z_{au} \end{aligned}\right\} \quad (41)$$

Consequently the following relations are true:

$$\left.\begin{aligned}
S^0 Z_{bw0} &= \frac{a + a^2}{2} S^0 Z_{au0} \\
S^0 Z_{cv0} &= \frac{a + a^2}{2} S^0 Z_{au0} \\
S^1 Z_{bw1} &= \frac{1 + a^2}{2} S^1 Z_{au1} \\
S^2 Z_{bw2} &= \frac{1 + a}{2} S^2 Z_{au2} \\
S^1 Z_{cv1} &= \frac{1 + a}{2} S^1 Z_{au1} \\
S^2 Z_{cv2} &= \frac{1 + a^2}{2} S^2 Z_{au2}
\end{aligned}\right\} \quad (42)$$

Substituting these relations in (**30**) and (**33**) we have for this system of mutual impedances

$$\left.\begin{aligned}
Z_{au0} + Z_{bw0} + Z_{cv0} &= 0 \\
Z_{au0} + a\, Z_{bw0} + a^2 Z_{cv0} &= 1\tfrac{1}{2}\, Z_{cv0} \\
Z_{au0} + a^2 Z_{bw0} + a\, Z_{cv0} &= 1\tfrac{1}{2}\, Z_{aw0}
\end{aligned}\right\} \quad (43)$$

$$\left.\begin{aligned}
Z_{au1} + Z_{bw1} + Z_{cv1} &= 1\tfrac{1}{2}\, Z_{au1} \\
Z_{au1} + a\, Z_{bw1} + a^2 Z_{cv1} &= 1\tfrac{1}{2}\, Z_{au1} \\
Z_{au1} + a^2 Z_{bw1} + a\, Z_{cv1} &= 0
\end{aligned}\right\} \quad (44)$$

$$\left.\begin{aligned}
Z_{au2} + Z_{bw2} + Z_{cv2} &= 1\tfrac{1}{2}\, Z_{au2} \\
Z_{au2} + a\, Z_{bw2} + a^2 Z_{cv2} &= 0 \\
Z_{au2} + a^2 Z_{bw2} + a\, Z_{cv2} &= 1\tfrac{1}{2}\, Z_{au2}
\end{aligned}\right\} \quad (45)$$

which on substitution in (**30**) and (**33**) gives

$$\left.\begin{aligned}
S^0 \check{E}_{a0} &= 0 \\
S^1 \check{E}_{a1} &= S^1 \{1\tfrac{1}{2}\, Z_{au1} \check{I}_{u0} + 1\tfrac{1}{2}\, Z_{au0} \check{I}_{u1} + 1\tfrac{1}{2}\, Z_{au2} \check{I}_{u2}\} \\
S^2 \check{E}_{a2} &= S^2 \{1\tfrac{1}{2}\, Z_{au2} \check{I}_{u0} + 1\tfrac{1}{2}\, Z_{au1} \check{I}_{u1} + 1\tfrac{1}{2}\, Z_{au0} \check{I}_{u2}\}
\end{aligned}\right\} \quad (46)$$

$$\left.\begin{aligned}
S^0 \check{E}_{u0} &= S^0 \{1\tfrac{1}{2}\, Z_{au2} \check{I}_{a1} + 1\tfrac{1}{2}\, Z_{au1} \check{I}_{a2}\} \\
S^1 \check{E}_{u1} &= S^1 \{1\tfrac{1}{2}\, Z_{au0} \check{I}_{a1} + 1\tfrac{1}{2}\, Z_{au2} \check{I}_{a2}\} \\
S^2 \check{E}_{u2} &= S^2 \{1\tfrac{1}{2}\, Z_{au1} \check{I}_{a1} + 1\tfrac{1}{2}\, Z_{au0} \check{I}_{a2}\}
\end{aligned}\right\} \quad (47)$$

The above symmetrical forms in which the factors $\cos\frac{2\pi}{3}$ and $\cos\frac{4\pi}{3}$ occur apply particularly to electromagnetic induction between windings distributed over the surfaces of co-axial cylinders; where if the plane of symmetry of one winding be taken as the datum plane, the mutual impedance between this winding and any other is a harmonic function of the angle between its plane of symmetry and the datum plane. In other words, the mutual impedances are functions of position on the circumference of a circle and may therefore be expanded by Fourier's theorem in a series of integral harmonics of the angle made by the planes of symmetry with the datum plane. Since the same procedure applies to all the terms of the expansion it is necessary only to consider the simple harmonic case. In the partially symmetrical cases of mutual induction, such as that taken up in the preceding discussion, there will be a difference between two possible cases, viz:—Symmetrical primary, unsymmetrical secondary, which is the case just considered, and unsymmetrical primary and symmetrical secondary in which the impedances of (**26**) will have the following values

$$\left.\begin{array}{llll}
\text{(I)} & Z_{au}, & Z_{bc}, & Z_{cw} \\
\text{(II)} & \frac{a+a^2}{2} Z_{bc}, & \frac{a+a^2}{2} Z_{cw}, & \frac{a+a^2}{2} Z_{au} \\
\text{(III)} & \frac{a+a^2}{2} Z_{cw}, & \frac{a+a^2}{2} Z_{au}, & \frac{a+a^2}{2} Z_{bc}
\end{array}\right\} \quad (\mathbf{48})$$

The results may be immediately set down by symmetry from equations (**46**) and (**47**), but the difference between the two cases will be better appreciated by setting down the component symmetrical impedances, thus we have

$$\left.\begin{aligned}
S^0 Z_{bw0} &= \frac{a+a^2}{2} S^0 Z_{au0} \\
S^0 Z_{cv0} &= \frac{a+a^2}{2} S^0 Z_{au0} \\
S^1 Z_{bw1} &= \frac{1+a}{2} S^1 Z_{au1} \\
S^2 Z_{bw2} &= \frac{1+a^2}{2} S^2 Z_{au2} \\
S^1 Z_{cv1} &= \frac{1+a^2}{2} S^1 Z_{cu1} \\
S^2 Z_{cv2} &= \frac{1+a}{2} S^2 Z_{au2}
\end{aligned}\right\} \quad (\mathbf{49})$$

Substituting these relations in the impedances used in (**30**) and (**33**) they become

$$\left.\begin{aligned} Z_{au0} + Z_{bw0} + Z_{cv0} &= 0 \\ Z_{au0} + a\, Z_{bw0} + a^2\, Z_{cv0} &= 1\tfrac{1}{2}\, Z_{au0} \\ Z_{au0} + a^2\, Z_{bw0} + a\, Z_{cv0} &= 1\tfrac{1}{2}\, Z_{au0} \end{aligned}\right\} \quad (50)$$

$$\left.\begin{aligned} Z_{au1} + Z_{bw1} + Z_{cv1} &= 1\tfrac{1}{2}\, Z_{au1} \\ Z_{au1} + a\, Z_{bw1} + a^2\, Z_{cv1} &= 0 \\ Z_{au1} + a^2\, Z_{bw1} + a\, Z_{cv1} &= 1\tfrac{1}{2}\, Z_{au1} \end{aligned}\right\} \quad (51)$$

$$\left.\begin{aligned} Z_{au2} + Z_{bw2} + Z_{cv2} &= 1\tfrac{1}{2}\, Z_{au2} \\ Z_{au2} + a\, Z_{bw2} + a^2\, Z_{cv2} &= 1\tfrac{1}{2}\, Z_{au2} \\ Z_{au2} + a^2\, Z_{bw2} + a\, Z_{cv2} &= 0 \end{aligned}\right\} \quad (52)$$

And we have from (**30**) and (**33**), or by symmetry

$$\left.\begin{aligned} S^0\, \check{E}_{a0} &= S^0\, \{1\tfrac{1}{2}\, Z_{au2}\, \check{I}_{u1} + 1\tfrac{1}{2}\, Z_{au1}\, \check{I}_{u2}\} \\ S^1\, \check{E}_{a1} &= S^1\, \{1\tfrac{1}{2}\, Z_{au0}\, \check{I}_{u1} + 1\tfrac{1}{2}\, Z_{au2}\, \check{I}_{u2}\} \\ S^2\, \check{E}_{a2} &= S^2\, \{1\tfrac{1}{2}\, Z_{au1}\, \check{I}_{u1} + 1\tfrac{1}{2}\, Z_{au0}\, \check{I}_{u2} \end{aligned}\right\} \quad (53)$$

$$\left.\begin{aligned} S^0\, \check{E}_{u0} &= 0 \\ S^1\, \check{E}_{u1} &= S^1\, \{1\tfrac{1}{2}\, Z_{au1}\, \check{I}_{a0} + 1\tfrac{1}{2}\, Z_{au0}\, \check{I}_{u1} + 1\tfrac{1}{2}\, Z_{au2}\, \check{I}_{u2}\} \\ S^2\, \check{E}_{u2} &= S^2\, \{1\tfrac{1}{2}\, Z_{au2}\, \check{I}_{a0} + 1\tfrac{1}{2}\, Z_{au1}\, \check{I}_{u1} + 1\tfrac{1}{2}\, Z_{au0}\, \check{I}_{u2}\} \end{aligned}\right\} \quad (54)$$

If the angle between the planes of symmetry of the coils and the datum plane are subject to changes, $\cos\dfrac{2\pi}{3}$ and $\cos\dfrac{4\pi}{3}$ in the preceding discussion must be replaced by

$$\left.\begin{aligned} \cos\left(\frac{2\pi}{3} + \theta\right) &= \frac{a}{2}\, e^{j\theta} + \frac{a^2}{2}\, e^{-j\theta} \\ \cos\left(\frac{4\pi}{3} + \theta\right) &= \frac{a}{2}\, e^{-j\theta} + \frac{a^2}{2}\, e^{j\theta} \end{aligned}\right\} \quad (55)$$

where θ is measured from the datum plane

In the strictly symmetrical case of co-axial cylindrical surface windings in which the members of each group of mutual

impedances are equal, the result of substituting (**55**) in the equations for induced e.m.f. will be

$$\left.\begin{aligned} S^0\,\check{E}_{a0} &= 0 \\ S^1\,\check{E}_{a1} &= S^1\,(1\tfrac{1}{2}\,Z_{au0}\,e^{j\theta}\;\check{I}_{u1}) \\ S^2\,\check{E}_{a2} &= S^2\,(1\tfrac{1}{2}\,Z_{au0}\,e^{-j\theta}\;\check{I}_{u2}) \end{aligned}\right\} \qquad (56)$$

$$\left.\begin{aligned} S^0\,\check{E}_{u0} &= 0 \\ S^1\,\check{E}_{u1} &= S^1\,(1\tfrac{1}{2}\,Z_{au0}\,e^{-j\theta}\;\check{I}_{a1}) \\ S^2\,\check{E}_{u2} &= S^2\,(1\tfrac{1}{2}\,Z_{au0}\,e^{j\theta}\;\check{I}_{a2}) \end{aligned}\right\} \qquad (57)$$

In the case having symmetrical primary and unsymmetrical secondary in which members of each group are different, but in which there are harmonic relations between corresponding members of the different groups, the impedances are

$$\left.\begin{array}{l} \text{(I)}\; Z_{au},\quad Z_{bv},\quad Z_{cw} \\ \text{(II)}\left(\dfrac{a}{2}\,e^{j\theta} + \dfrac{a^2}{2}\,e^{-j\theta}\right) Z_{cw} \\ \left(\dfrac{a}{2}\,e^{j\theta} + \dfrac{a^2}{2}\,e^{-j\theta}\right) Z_{au},\; \left(\dfrac{a}{2}\,e^{j\theta} + \dfrac{a^2}{2}\,e^{-j\theta}\right) Z_{bv} \\ \text{(III)}\left(\dfrac{a^2}{2}\,e^{j\theta} + \dfrac{a}{2}\,e^{-j\theta}\right) Z_{bv}, \\ \left(\dfrac{a^2}{2}\,e^{j\theta} + \dfrac{a}{2}\,e^{-j\theta}\right) Z_{cw},\; \left(\dfrac{a^2}{2}\,e^{j\theta} + \dfrac{a}{2}\,e^{-j\theta}\right) Z_{au} \end{array}\right\} \qquad (58)$$

The symmetrical component mutual impedances will have the following values in terms of $Z_{au0}\;Z_{au1}\;Z_{au2}$

$$\left.\begin{aligned} S^0\,Z_{bw0} &= \left(\frac{a}{2}\,e^{j\theta} + \frac{a^2}{2}\,e^{-j\theta}\right) S^0\,Z_{au0} \\ S^0\,Z_{cv0} &= \left(\frac{a^2}{2}\,e^{j\theta} + \frac{a}{2}\,e^{-j\theta}\right) S^0\,Z_{au0} \\ S^1\,Z_{bw1} &= \left(\frac{a^2}{2}\,e^{j\theta} + \frac{e^{-j\theta}}{2}\right) S^1\,Z_{au1} \\ S^2\,Z_{bw2} &= \left(\frac{e^{j\theta}}{2} + \frac{a}{2}\,e^{-j\theta}\right) S^2\,Z_{au2} \\ S^1\,Z_{cv1} &= \left(\frac{a}{2}\,e^{j\theta} + \frac{e^{-j\theta}}{2}\right) S^1\,Z_{au1} \\ S^2\,Z_{cv2} &= \left(\frac{e^{j\theta}}{2} + \frac{a^2}{2}\,e^{-j\theta}\right) S^2\,Z_{au2} \end{aligned}\right\} \qquad (59)$$

Substituting these relations in the impedances of equations (**30**) and (**33**) they become

$$\left.\begin{aligned} Z_{au0} + Z_{bw0} + Z_{cv0} &= 0 \\ Z_{au0} + a\,Z_{bw0} + a^2\,Z_{cv0} &= 1\tfrac{1}{2}\,Z_{au0}\,e^{-j\theta} \\ Z_{au0} + a^2\,Z_{bw0} + a\,Z_{cv0} &= 1\tfrac{1}{2}\,Z_{au0}\,e^{j\theta} \end{aligned}\right\} \quad (60)$$

$$\left.\begin{aligned} Z_{au1} + Z_{bw1} + Z_{cv1} &= 1\tfrac{1}{2}\,Z_{au1}\,e^{-j\theta} \\ Z_{au1} + a\,Z_{bw1} + a^2\,Z_{cv1} &= 1\tfrac{1}{2}\,Z_{au1}\,e^{j\theta} \\ Z_{au1} + a^2\,Z_{bw1} + a\,Z_{cv1} &= 0 \end{aligned}\right\} \quad (61)$$

$$\left.\begin{aligned} Z_{au2} + Z_{bw2} + Z_{cv2} &= 1\tfrac{1}{2}\,Z_{au2}\,e^{j\theta} \\ Z_{au2} + a\,Z_{bw2} + a^2\,Z_{cv2} &= 0 \\ Z_{au2} + a^2\,Z_{bw2} + a\,Z_{cv2} &= 1\tfrac{1}{2}\,Z_{au}\,e^{-j\theta} \end{aligned}\right\} \quad (62)$$

which on substitution in (**30**) and (**33**) give

$$\left.\begin{aligned} S^0\,\check{E}_{a0} &= 0 \\ S^1\,\check{E}_{a1} &= S^1\,\{1\tfrac{1}{2}\,Z_{au1}\,e^{j\theta}\,\check{I}_{u0} + 1\tfrac{1}{2}\,Z_{au0}\,e^{j\theta}\,\check{I}_{u1} \\ &\qquad + 1\tfrac{1}{2}\,Z_{au2}\,e^{j\theta}\,\check{I}_{u2}\} \\ S^2\,\check{E}_{a2} &= S^2\,\{1\tfrac{1}{2}\,Z_{au2}\,e^{-j\theta}\,\check{I}_{u0} + 1\tfrac{1}{2}\,Z_{au1}\,e^{-j\theta}\,\check{I}_{u1} \\ &\qquad + 1\tfrac{1}{2}\,Z_{au0}\,e^{-j\theta}\,\check{I}_{u2}\} \end{aligned}\right\} \quad (63)$$

$$\left.\begin{aligned} S^0\,\check{E}_{u0} &= S^0\,\{1\tfrac{1}{2}\,Z_{au2}\,e^{-j\theta}\,\check{I}_{a1} + 1\tfrac{1}{2}\,Z_{au1}\,e^{j\theta}\,\check{I}_{a2}\} \\ S^1\,\check{E}_{u1} &= S^1\,\{1\tfrac{1}{2}\,Z_{au0}\,e^{-j\theta}\,\check{I}_{a1} + 1\tfrac{1}{2}\,Z_{au2}\,e^{j\theta}\,\check{I}_{a2}\} \\ S^2\,\check{E}_{u2} &= S^2\,\{1\tfrac{1}{2}\,Z_{au1}\,e^{-j\theta}\,\check{I}_{a1} + 1\tfrac{1}{2}\,Z_{au0}\,e^{j\theta}\,\check{I}_{a2}\} \end{aligned}\right\} \quad (64)$$

In the case of unsymmetrical primary and symmetrical secondary, we have for the value of the impedance in terms of Z_{au0} Z_{au1} and Z_{au2}

$$\left.\begin{aligned} &\text{(I)}\ Z_{au},\quad Z_{bv},\quad Z_{cw} \\ &\text{(II)}\left(\frac{a}{2}\,e^{j\theta} + \frac{a^2}{2}\,e^{-j\theta}\right) Z_{bc}, \\ &\left(\frac{a}{2}\,e^{j\theta} + \frac{a^2}{2}\,e^{-j\theta}\right) Z_{cw},\ \left(\frac{a}{2}\,e^{j\theta} + \frac{a^2}{2}\,e^{-j\theta}\right) Z_{au} \\ &\text{(III)}\left(\frac{a^2}{2}\,e^{j\theta} + \frac{a}{2}\,e^{-j\theta}\right) Z_{cw}, \\ &\left(\frac{a^2}{2}\,e^{j\theta} + \frac{a}{2}\,e^{-j\theta}\right) Z_{au},\ \left(\frac{a^2}{2}\,e^{j\theta} + \frac{a}{2}\,e^{-j\theta}\right) Z_{bc} \end{aligned}\right\} \quad (65)$$

The symmetrical component mutual impedances in terms of Z_{au0}, Z_{au1}, Z_{au2} are

$$\left.\begin{aligned}
S^0\, Z_{bw0} &= \left(\frac{a}{2}\, e^{j\theta} + \frac{a^2}{2}\, e^{-j\theta}\right) S^0\, Z_{au0} \\
S^0\, Z_{cv0} &= \left(\frac{a^2}{2}\, e^{j\theta} + \frac{a}{2}\, e^{-j\theta}\right) S^0\, Z_{au0} \\
S^1\, Z_{bw1} &= \left(\frac{e^{j\theta}}{2} + \frac{a}{2}\, e^{-j\theta}\right) S^1\, Z_{au1} \\
S^2\, Z_{bw2} &= \left(\frac{a^2}{2}\, e^{j\theta} + \frac{e^{-j\theta}}{2}\right) S^2\, Z_{au2} \\
S^1\, Z_{cv1} &= \left(\frac{e^{j\theta}}{2} + \frac{a^2}{2}\, e^{-j\theta}\right) S^1\, Z_{au1} \\
S^2\, Z_{cv2} &= \left(\frac{a}{2}\, e^{j\theta} + \frac{e^{-j\theta}}{2}\right) S^2\, Z_{au2}
\end{aligned}\right\} \qquad (66)$$

And the impedances of equations (**30**) and (**33**) become

$$\left.\begin{aligned}
Z_{au0} + Z_{bw0} + Z_{cv0} &= 0 \\
Z_{au0} + a\, Z_{bw0} + a^2\, Z_{cv0} &= 1\tfrac{1}{2}\, Z_{au0}\, e^{-j\theta} \\
Z_{au0} + a^2\, Z_{bw0} + a\, Z_{cv0} &= 1\tfrac{1}{2}\, Z_{au0}\, e^{j\theta}
\end{aligned}\right\} \qquad (67)$$

$$\left.\begin{aligned}
Z_{au1} + Z_{bw1} + Z_{cv1} &= 1\tfrac{1}{2}\, Z_{au1}\, e^{j\theta} \\
Z_{au1} + a\, Z_{bw1} + a^2\, Z_{cv1} &= 0 \\
Z_{au1} + a^2\, Z_{bw1} + a\, Z_{cv1} &= 1\tfrac{1}{2}\, Z_{au1}\, e^{-j\theta}
\end{aligned}\right\} \qquad (68)$$

$$\left.\begin{aligned}
Z_{au2} + Z_{bw2} + Z_{cv2} &= 1\tfrac{1}{2}\, Z_{au2}\, e^{-j\theta} \\
Z_{au2} + a\, Z_{bw2} + a^2\, Z_{cv2} &= 1\tfrac{1}{2}\, Z_{au2}\, e^{j\theta} \\
Z_{au2} + a^2\, Z_{bw} + a\, Z_{cv2} &= 0
\end{aligned}\right\} \qquad (69)$$

And on substitution in (**30**) and (**33**), or by symmetry from (**63**) and (**64**), we have

$$\left.\begin{aligned}
S^0\, \breve{E}_{a0} &= S^0\, \{1\tfrac{1}{2}\, Z_{au2}\, e^{j\theta}\, \breve{I}_{u1} + 1\tfrac{1}{2}\, Z_{au1}\, e^{-j\theta}\, \breve{I}_{u2}\} \\
S^1\, \breve{E}_{a1} &= S^1\, \{1\tfrac{1}{2}\, Z_{au0}\, e^{j\theta}\, \breve{I}_{u1} + 1\tfrac{1}{2}\, Z_{au2}\, e^{-j\theta}\, \breve{I}_{u2}\} \\
S^2\, \breve{E}_{a2} &= S^2\, \{1\tfrac{1}{2}\, Z_{au1}\, e^{j\theta}\, \breve{I}_{u1} + 1\tfrac{1}{2}\, Z_{au0}\, e^{-j\theta}\, \breve{I}_{u2}\}
\end{aligned}\right\} \qquad (70)$$

$$\left.\begin{aligned}
S^0\,\check{E}_{u0} &= 0\\
S^1\,\check{E}_{u1} &= S^1\,\{1\tfrac{1}{2}\,Z_{au1}\,e^{-j\theta}\,\check{I}_{a0} + 1\tfrac{1}{2}\,Z_{au0}\,e^{-j\theta}\,\check{I}_{u1}\\
&\qquad + 1\tfrac{1}{2}\,Z_{au2}\,e^{-j\theta}\,\check{I}_{a2}\}\\
S^2\,\check{E}_{u2} &= S^2\,\{1\tfrac{1}{2}\,Z_{au2}\,e^{j\theta}\,\check{I}_{a0} + 1\tfrac{1}{2}\,Z_{au1}\,e^{j\theta}\,\check{I}_{a1}\\
&\qquad + 1\tfrac{1}{2}\,Z_{au0}\,e^{j\theta}\,\check{I}_{a2}\}
\end{aligned}\right\}\qquad (71)$$

A fuller discussion of self and mutual impedances of co-axial cylindrical windings will be found in the Appendix. It will be sufficient to note here that in the case of self inductance and mutual inductance of stationary windings symmetrically disposed if they are equal

$$\left.\begin{aligned}
M_{ab} = M_{bc} = M_{ca} &= \Sigma\left(A_n \cos\frac{2\,n\,\pi}{3}\right)\\
L_{aa} = L_{bb} = L_{cc} = M_{aa} = M_{bb} = M_{cc} &= \Sigma\,A_n
\end{aligned}\right\}\qquad (72)$$

If the windings are symmetrically disposed but have different number of turns

$$\left.\begin{aligned}
L_{aa} &= M_{aa} = \Sigma\,A_n\\
L_{bb} &= M_{bb} = \Sigma\,B_n\\
L_{cc} &= M_{cc} = \Sigma\,C_n
\end{aligned}\right\}\qquad (73)$$

$$\left.\begin{aligned}
M_{ab} &= \Sigma\left(\sqrt{A_n\,B_n}\cos\frac{2\,n\,\pi}{3}\right)\\
M_{bc} &= \Sigma\left(\sqrt{B_n\,C_n}\cos\frac{2\,n\,\pi}{3}\right)\\
M_{ca} &= \Sigma\left(\sqrt{C_n\,A_n}\cos\frac{2\,n\,\pi}{3}\right)
\end{aligned}\right\}\qquad (74)$$

If the coils are alike but unsymmetrically spaced $L_{aa}\ L_{bb}\ L_{cc}$ have the same values, namely $\Sigma\,A_n$ and

$$\left.\begin{aligned}
M_{ab} &= \Sigma\left\{(A_n \cos n\,\theta_1)\cos\frac{2\,n\,\pi}{3} + (A_n \sin n\,\theta_1)\sin\frac{2\,n\,\pi}{3}\right\}\\
M_{bc} &= \Sigma\left\{(A_n \cos n\,\theta_2)\cos\frac{2\,n\,\pi}{3} + (A_n \sin n\,\theta_2)\sin\frac{2\,n\,\pi}{3}\right\}\\
M_{ca} &= \Sigma\left\{(A_n \cos n\,\theta_3)\cos\frac{2\,n\,\pi}{3} + (A_n \sin n\,\theta_3)\sin\frac{2\,n\,\pi}{3}\right\}
\end{aligned}\right\}\qquad (75)$$

If they are unequal as well as unsymmetrically disposed but are otherwise similar L_{aa} L_{bb} L_{cc} have values as in (**64**) and

$$\left.\begin{aligned}
M_{ab} &= \Sigma \left\{ (\sqrt{A_n\,B_n} \cos n\,\theta_1) \cos \frac{2\,n\,\pi}{3} \right. \\
&\qquad \left. + (\sqrt{A_n\,B_n} \sin n\,\theta_1) \sin \frac{2\,n\,\pi}{3} \right\} \\
M_{bc} &= \Sigma \left\{ (\sqrt{B_n\,C_n} \cos n\,\theta_2) \cos \frac{2\,n\,\pi}{3} \right. \\
&\qquad \left. + (\sqrt{B_n\,C_n} \sin n\,\theta_2) \sin \frac{2\,n\,\pi}{3} \right\} \\
M_{ca} &= \Sigma \left\{ (\sqrt{C_n\,A_n} \cos n\,\theta_1) \cos \frac{2\,n\,\pi}{3} \right. \\
&\qquad \left. + (\sqrt{C_n\,A_n} \sin n\,\theta_3) \sin \frac{2\,n\,\pi}{3} \right\}
\end{aligned}\right\} \quad (\mathbf{76})$$

Where the windings are dissimilar in every respect the expressions become more complicated. A short outline of this subject is given in the Appendix.

In the case of mutual inductance between two coaxial cylindrical systems, one of which A, B, C is the primary and the other U, V, W the secondary, the following conventions should be followed:

(a) All angles are measured, taking the primary planes of symmetry as data in a positive direction.

(b) The datum plane for all windings is the plane of symmetry of the primary A phase.

(c) All mechanical motions unless otherwise stated shall be considered as positive rotations of the secondary cylinder about its axis.

(d) The conventional disposition of the phases and the direction of rotation of the secondary winding are indicated in Fig. 3.

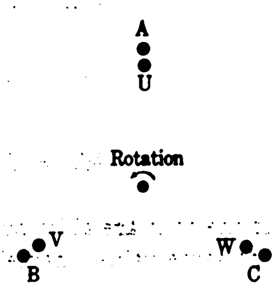

FIG. 3—CONVENTIONAL DISPOSITION OF PHASES AND DIRECTION OF ROTATION.

We shall consider five cases; Case 1 being the completely symmetrical case and the rest being symmetrical in one winding, the other winding being unsymmetrical in magnitude and phase, or both, but all windings having the same form and distribution of coils.

Case I. All Windings Symmetrical.

$$\left.\begin{aligned}
M_{au} &= M_{bv} = M_{cw} = \Sigma A_n \cos n\,\theta \\
M_{bw} &= M_{cu} = M_{av} = \Sigma A_n \cos n\left(\frac{2\pi}{3}+\theta\right) \\
M_{cv} &= M_{aw} = M_{bu} = \Sigma A_n \cos n\left(\frac{4\pi}{3}+\theta\right)
\end{aligned}\right\} \quad (77)$$

Case II. Primary Windings equal and Symmetrical, Secondary Windings unequal but otherwise Symmetrical.

$$\left.\begin{aligned}
M_{au} &= \Sigma A_n \cos n\,\theta,\ M_{bv} = \Sigma B_n \cos n\,\theta,\ M_{cw} \\
&= \Sigma C_u \cos n\,\theta \\
M_{bw} &= \Sigma C_u \cos n\left(\frac{2\pi}{3}+\theta\right), \\
M_{cu} &= \Sigma A_n \cos n\left(\frac{2\pi}{3}+\theta\right), \\
M_{av} &= \Sigma B_n \cos n\left(\frac{2\pi}{3}+\theta\right) \\
M_{cv} &= \Sigma B_n \cos n\left(\frac{4\pi}{3}+\theta\right), \\
M_{aw} &= \Sigma C_n \cos n\left(\frac{4\pi}{3}+\theta\right), \\
M_{bu} &= \Sigma A_n \cos n\left(\frac{4\pi}{3}+\theta\right)
\end{aligned}\right\} \quad (78)$$

Case III. Primary Winding Unequal but Otherwise Symmetrical, Secondary Winding &qual and Symmetrical.

$$\left.\begin{aligned}
&M_{au} = \Sigma A_n \cos n\,\theta, M_{bv} = \Sigma B_n \cos n\,\theta,\ M_{cw} = \Sigma C_n \cos n\theta \\
&M_{bw} = \Sigma B_n \cos n\left(\frac{2\pi}{3}+\theta\right), \\
&M_{cu} = \Sigma C_n \cos n\left(\frac{2\pi}{3}+\theta\right) \\
&M_{av} = \Sigma A_n \cos n\left(\frac{2\pi}{3}+\theta\right) \\
&M_{cv} = \Sigma C_n \cos n\left(\frac{4\pi}{3}+\theta\right), \\
&M_{aw} = \Sigma A_n \cos n\left(\frac{4\pi}{3}+\theta\right), \\
&M_{bu} = \Sigma B_n \cos n\left(\frac{4\pi}{3}+\theta\right)
\end{aligned}\right\} \quad (79)$$

Case IV. Same as Case II except in addition to inequality Secondary Windings are Displaced from Symmetry by angles α_1 α_2 and α_3 whose sum is zero.

$$\left.\begin{aligned}
M_{au} &= \Sigma\,(A_n \cos\alpha_1 \cos n\,\theta + A_n \sin\alpha_1 \sin n\,\theta)\\
M_{bv} &= \Sigma\,(B_n \cos\alpha_2 \cos n\,\theta + B_n \sin\alpha_2 \sin n\,\theta)\\
M_{cw} &= \Sigma\,(C_n \cos\alpha_3 \cos n\,\theta + C_n \sin\alpha_3 \sin n\,\theta)\\
M_{bw} &= \Sigma\left\{C_n \cos\alpha_3 \cos n\left(\frac{2\,\pi}{3} + \theta\right)\right.\\
&\qquad \left. + C_n \sin\alpha_3 \sin n\left(\frac{2\,\pi}{3} + \theta\right)\right\}\\
M_{cu} &= \Sigma\left\{A_n \cos\alpha_1 \cos n\left(\frac{2\,\pi}{3} + \theta\right)\right.\\
&\qquad \left. + A_n \sin\alpha_1 \sin n\left(\frac{2\,\pi}{3} + \theta\right)\right\}\\
M_{av} &= \Sigma\left\{B_n \cos\alpha_2 \cos n\left(\frac{2\,\pi}{3} + \theta\right)\right.\\
&\qquad \left. + B_n \sin\alpha_2 \sin n\left(\frac{2\,\pi}{3} + \theta\right)\right\}\\
M_{cv} &= \Sigma\left\{B_n \cos\alpha_2 \cos n\left(\frac{4\,\pi}{3} + \theta\right)\right.\\
&\qquad \left. + B_n \sin\alpha_2 \sin n\left(\frac{4\,\pi}{3} + \theta\right)\right\}\\
M_{aw} &= \Sigma\left\{C_n \cos\alpha_3 \cos n\left(\frac{4\,\pi}{3} + \theta\right)\right.\\
&\qquad \left. + C_n \sin\alpha_3 \sin n\left(\frac{4\,\pi}{3} + \theta\right)\right\}\\
M_{bu} &= \Sigma\left\{A_n \cos\alpha_1 \cos n\left(\frac{4\,\pi}{3} + \theta\right)\right.\\
&\qquad \left. + A_n \sin\alpha_1 \sin n\left(\frac{4\,\pi}{3} + \theta\right)\right\}
\end{aligned}\right\} \quad (80)$$

Case V. Same as Case III except that the Primary Windings are Unsymmetrically disposed with respect to one another as well as being unequal.

$$
\left.\begin{aligned}
M_{au} &= \Sigma\,(A_n \cos \alpha_1 \cos n\,\theta + A_n \sin \alpha_1 \sin n\,\theta) \\
M_{bv} &= \Sigma\,(B_n \cos \alpha_2 \cos n\,\theta + B_n \sin \alpha_2 \sin n\,\theta) \\
M_{cw} &= \Sigma\,(C_n \cos \alpha_3 \cos n\,\theta + C_n \sin \alpha_3 \sin n\,\theta) \\
M_{bw} &= \Sigma \left\{ B_n \cos \alpha_2 \cos n \left(\frac{2\pi}{3} + \theta\right) + B_n \sin \alpha_2 \sin n \left(\frac{2\pi}{3} + \theta\right)\right\} \\
M_{cu} &= \Sigma \left\{ A_n \cos \alpha_1 \cos n \left(\frac{2\pi}{3} + \theta\right) + A_n \sin \alpha_1 \sin n \left(\frac{2\pi}{3} + \theta\right)\right\} \\
M_{av} &= \Sigma \left\{ C_n \cos \alpha_3 \cos n \left(\frac{2\pi}{3} + \theta\right) + C_u \sin \alpha_3 \sin n \left(\frac{2\pi}{3} + \theta\right)\right\} \\
M_{cv} &= \Sigma \left\{ C_n \cos \alpha_3 \cos n \left(\frac{4\pi}{3} + \theta\right) + C_n \sin \alpha_3 \sin n \left(\frac{4\pi}{3} + \theta\right)\right\} \\
M_{aw} &= \Sigma \left\{ A_n \cos \alpha_1 \cos n \left(\frac{4\pi}{3} + \theta\right) + A_n \sin \alpha_1 \sin n \left(\frac{4\pi}{3} + \theta\right)\right\} \\
M_{bu} &= \Sigma \left\{ B_n \cos \alpha_2 \cos n \left(\frac{4\pi}{3} + \theta\right) + B_n \sin \alpha_2 \sin n \left(\frac{4\pi}{3} + \theta\right)\right\}
\end{aligned}\right\} \quad (81)
$$

The expressions for dissymmetry in both windings and for unsymmetrically wound coils, etc., are more complicated and will be dealt with in the Appendix.

The impedances Z_{aa} Z_{bb}, etc., Z_{au} Z_{bv}, etc., are functions of M_{ac} M_{bb}, etc., M_{au} M_{bv}, etc., and the resistances of the system. The component of e. m. f. proportional to the current due to

mutual impedance is so small that it may generally be neglected so that Z_{au} becomes $\frac{d}{dt}\ M_{au},\ Z_{br}\ =\ \frac{d}{dt}\ M_{br}$ and so forth.

If the secondary winding is rotating at an angular velocity α, θ in equation (**55**) becomes $\alpha\ t$ and the operators Z_{aa}, etc. operate on such products as $e^{j\alpha t}\ \check{I}_{u1}\quad e^{j\alpha t}\ \check{I}_{u2}$ where $\check{I}_{u1}$ and $\check{I}_{u2}$ are three variables.

The following relations will be found useful in the application of the method in actual examples.

If D denotes the operator $\frac{d}{d\,x}$ and $\varphi\ (Z)$ is a rational algebraic function of Z

$$\left.\begin{aligned} \varphi\ (D)\ e^{ax} &= \varphi\ (a)\ e^{ax} \\ \varphi\ (D)\ \{e^{ax}\ \ X\} &= e^{ax}\ \ \varphi\ (D + a)\ X \\ \varphi\ (D)\ Y &= e^{ax}\,\varphi\ (D + a)\ Y\ e^{-ax} \end{aligned}\right\} \qquad \textbf{(82)}$$

Where X and Y may be any function of x.

Star and Delta e.m.fs. and Currents in Terms of Symmetrical Components

It has been shown in the preceding portion of this paper that the e. m. fs. $\check{E}_a\ \check{E}_b$ and $\check{E}_c$ and the currents $\check{I}_a\ \check{I}_b$ and $\check{I}_c$ whatever their distortion, may be represented by the sum of symmetrical systems of e. m. fs. or currents so that the two expressions

$$\left.\begin{aligned} S\ (\check{E}_a) &= S^0\ \check{E}_{a0} + S^1\ \check{E}_{a1} + S^2\ \check{E}_{a2} \\ S\ (\check{I}_a) &= S^0\ \check{I}_{a0} + S^1\ \check{I}_{a1} + S^2\ \check{I}_{a2} \end{aligned}\right\} \qquad \textbf{(83)}$$

completely define these two systems.

If we take the delta e. m. fs. and currents corresponding to $S^0\ \check{E}_{a0}$, $S^1\ \check{E}_{a1}$ and $S^2\ \check{E}_{a2}$, $S^1\ \check{I}_{a1}$, $S^2\ \check{I}_{a2}$, we have, since $\check{E}_{bc1}$ leads $\check{E}_{a1}$ by $\frac{\pi}{2}$ and $\check{E}_{bc2}$ lags behind $\check{E}_{a2}$ by the same angle

$$\left.\begin{aligned} S^0\ \check{E}_{bc0} &= 0 \\ S^1\ \check{E}_{bc1} &= j\ \sqrt{3}\ S^1\ \check{E}_{a1} \\ S^2\ \check{E}_{bc2} &= -\ j\ \sqrt{3}\ S^2\ \check{E}_{a2} \\ S^0\ \check{I}_{bc0} &= \text{indeterminate from } S\ (\check{I}_a) \\ S^1\ \check{I}_{bc1} &= \ \ j\ \frac{1}{\sqrt{3}}\ S^1\ \check{I}_{a1} \\ S^2\ \check{I}_{bc2} &= -j\ \frac{1}{\sqrt{3}}\ S^2\ \check{I}_{a2} \end{aligned}\right\} \qquad \textbf{(84)}$$

And therefore if we take $\check{E}_{ab}$ as the principal vector

$$\left.\begin{aligned} S^0\,\check{E}_{ab0} &= 0 \\ S^1\,E_{ab1} &= j\,a\,\sqrt{3}\,\check{E}_{a1} \\ S^2\,\check{E}_{ab2} &= -j\,a^2\,\sqrt{3}\,\check{E}_{a2} \\ S\,(\check{E}_{ab}) &= S^1\,\check{E}_{ab1} + S^2\,\check{E}_{ab2} \end{aligned}\right\} \quad (85)$$

The last equation of group (**85**) when expanded gives

$$\left.\begin{aligned} \check{E}_{ab} &= j\,\sqrt{3}\,(a\,\check{E}_{a1} - a^2\,\check{E}_{a2}) \\ \check{E}_{bc} &= j\,\sqrt{3}\,(\check{E}_{a1} - \check{E}_{a2}) \\ \check{E}_{ca} &= j\,\sqrt{3}\,(a^2\,\check{E}_{a1} - a\,\check{E}_{a2}) \end{aligned}\right\} \quad (86)$$

which may also be obtained direct from (**83**) by means of the relations

$$\begin{aligned} \check{E}_{ab} &= \check{E}_b - \check{E}_a \\ \check{E}_{bc} &= \check{E}_c - \check{E}_b \\ \check{E}_{ca} &= \check{E}_a - \check{E}_0 \end{aligned}$$

Similarly

$$\begin{aligned} S^0\,\check{I}_{ab} &= \text{indeterminate from } S\,(\check{I}_a) \\ S^1\,\check{I}_{ab1} &= j\,a\,\frac{1}{\sqrt{3}}\,\check{I}_{a1} \\ S^2\,\check{I}_{ab2} &= j\,a^2\,\frac{1}{\sqrt{3}}\,\check{I}_{a2} \qquad\qquad (87) \\ S\,(\check{I}_{ab}) &= S^0\,\check{I}_{ab0} + S^1\,I_{ab1} + S^2\,\check{I}_{ab2} \end{aligned}$$

with similar expression for $\check{I}_{ab}$ $\check{I}_{bc}$ and $\check{I}_{ca}$ which may be verified by means of the relations

$$\begin{aligned} \check{I}_a &= \check{I}_{ca} - \check{I}_{ab} + \check{I}_{a0} \\ \check{I}_b &= \check{I}_{ab} - \check{I}_{bc} + \check{I}_{a0} \\ \check{I}_c &= \check{I}_{bc} - \check{I}_{ca} + \check{I}_{a0} \end{aligned}$$

Conversely to (**84**) we have the following relations

$$\left.\begin{aligned}
S^0\,\check{E}_{a0} &= \text{indeterminate from } S\,(\check{E}_{ab}) \\
S^1\,\check{E}_{a1} &= -\,j\frac{1}{\sqrt{3}}\,S^1\,\check{E}_{bc1} = -j\,\frac{a^2}{\sqrt{3}}\,S^1\,\check{E}_{ab1} \\
S^2\,\check{E}_{a2} &= j\,\frac{1}{\sqrt{3}}\,S^2\,E_{bc2} = j\,\frac{a}{\sqrt{3}}\,S^2\,E_{ab2} \\
S^0\,\check{I}_{a0} &= \text{indeterminate from } S\,(\check{I}_{ab}) \\
S^1\,\check{I}_{a1} &= -\,j\,\sqrt{3}\,S^1\,I_{bc1} = -\,j\,a^2\,\sqrt{3}\,S^1\,\check{I}_{ab1} \\
S^2\,\check{I}_{a2} &= j\,\sqrt{3}\,S^2\,\check{I}_{bc} = j\,a\,\sqrt{3}\,S^2\,\check{I}_{ab2}
\end{aligned}\right\} \qquad (88)$$

It will be sufficient in order to illustrate the application of the principle of symmetrical coordinates to simple circuits to apply it to a few simple cases of transformer connections before proceeding to its application to rotating polyphase systems to which it is particularly adapted.

Unsymmetrical Bank of Delta-Delta Transformers Operating on a Symmetrical Circuit Supplying a Balanced System

Let the transformer effective impedances be $Z_{AB}\ Z_{BC}\ Z_{CA}$ and let the secondary load currents be $\check{I}_U\ \check{I}_V$ and $\check{I}_W$ and let the star load impedance be Z. One to one ratio of transformation will be assumed, and the effect of the magnetizing current will be neglected. The symmetrical equations are

$$\left.\begin{aligned}
O &= S^0\,(Z_{AB0}\,\check{I}_{ab0} + Z_{AB2}\,\check{I}_{ab1} + Z_{AB1}\,\check{I}_{ab2}) \\
S^1\,\check{E}_{uv1} &= S^1\,\check{E}_{ab1} - S^1\,(Z_{AB1}\,\check{I}_{ab0} + Z_{AB0}\,\check{I}_{ab1} + Z_{AB2}\,\check{I}_{ab2}) \\
S^2\,\check{E}_{uv2} &= 0 - S^2\,(Z_{AB2}\,\check{I}_{ab0} + Z_{AB1}\,\check{I}_{ab1} + Z_{AB0}\,\check{I}_{ab2}) \\
S^0\,\check{I}_{u0} &= 0 \\
S^1\,Z\,\check{I}_{u1} &= \check{E}_{u1} \\
S^2\,Z\,\check{I}_{u2} &= \check{E}_{u2}
\end{aligned}\right\} \qquad (89)$$

Since the transformation ratio is unity and the effects of magnetizing currents are negligible $S^1\,\check{I}_{ab1} = S^1\,\check{I}_{UV1}$, $S^2\,\check{I}_{ab2} = S^2\,\check{I}_{UV2}$. And therefore by means of the relations (85), the last two equations may be expressed

$$\left.\begin{aligned} S^1 \check{E}_{uv1} &= S^1\, 3\, Z\, \check{I}_{ab1} \\ S^2 \check{E}_{uv2} &= S^2\, 3\, Z\, \check{I}_{ab2} \end{aligned}\right\} \quad (90)$$

in other words, the symmetrical components appear in the secondary as independent systems, $3\,Z$ being the delta load impedance equivalent to the star impedance Z.

Substituting from (**90**) in the second and third equation and eliminating $\check{I}_{ab0}$ by means of the first equation, and we have

$$\left.\begin{aligned} S^1 \check{E}_{ab1} = S^1 \Bigg\{ &\left(3\,Z + Z_{AB0} - \frac{Z_{AB1}\, Z_{AB2}}{Z_{AB0}} \right) \check{I}_{ab1} \\ &+ \left(Z_{AB2} - \frac{Z_{AB1}{}^2}{Z_{AB0}} \right) \check{I}_{ab2} \Bigg\} \\ S^2 O = S^2 \Bigg\{ &\left(Z_{AB1} - \frac{Z^2{}_{AB2}}{Z_{AB0}} \right) \check{I}_{ab1} \\ &+ \left(3\,Z + Z_{AB0} - \frac{Z_{AB1}\, Z_{AB2}}{Z_{AB0}} \right) \check{I}_{ab2} \Bigg\} \end{aligned}\right\} \quad (91)$$

which, when S^1 and S^2 are removed, give two simultaneous equations in $\check{I}_{ab1}$ and $\check{I}_{ab2}$.

A modification of the problem may occur even when the load impedances are symmetrical, as they may have symmetrical but unequal impedances Z_1 and Z_2, to the two components $\check{I}_{v1}$ and $\check{I}_{v2}$ respectively, as in the case of a load consisting of a symmetrical rotating machine. The equations corresponding to (**89**), (**90**) and (**91**) then become

$$\left.\begin{aligned} O &= S^0 (Z_{AB0}\, \check{I}_{ab0} + Z_{AB2}\, \check{I}_{ab1} + Z_{AB1}\, \check{I}_{ab2}) \\ S^1 \check{E}_{uv1} &= S^1 \check{E}_{ab1} - S^1 (Z_{AB1}\, \check{I}_{ab0} + Z_{AB0}\, \check{I}_{ab1} + Z_{AB2}\, \check{I}_{ab2}) \\ S^2 E_{uv2} &= O - S^2 (Z_{AB2}\, \check{I}_{ab0} + Z_{AB1}\, \check{I}_{ab1} + Z_{AB0}\, \check{I}_{ab2}) \\ S^0\, \check{I}_{u0} &= O \\ S^1 Z_1\, \check{I}_{u1} &= \check{E}_{u1} \\ S^2 Z_2\, \check{I}_{u2} &= \check{E}_{u2} \end{aligned}\right\} \quad (92)$$

$$\left.\begin{aligned} S^1 \check{E}_{uv1} &= S^1\, 3\, Z_1\, \check{I}_{ab1} \\ S^2 \check{E}_{uv2} &= S^2\, 3\, Z_2\, \check{I}_{ab2} \end{aligned}\right\} \quad (93)$$

$$\left.\begin{aligned} S^1 \check{E}_{ab1} &= S^1 \left\{ \left(3 Z_1 + Z_{AB0} - \frac{Z_{AB1}\, Z_{AB2}}{Z_{AB0}} \right) \check{I}_{ab1} \right. \\ &\qquad \left. + \left(Z_{AB2} - \frac{Z^2_{AB1}}{Z_{AB0}} \right) \check{I}_{ab2} \right\} \\ S^2\, O &= S^2 \left\{ \left(Z_{AB1} - \frac{Z^2_{AB1}}{Z_{AB0}} \right) \check{I}_{ab1} \right. \\ &\qquad \left. + \left(3 Z_2 + Z_{AB0} - \frac{Z_{AB1}\, Z_{AB2}}{Z_{AB0}} \right) \check{I}_{ab2} \right\} \end{aligned} \right\} \quad (94)$$

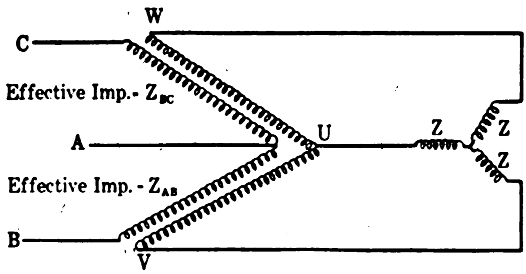

Fig. 4—Open Delta or V Connection.

In an open delta system $Z_{AB1} = Z_{AB2} = Z_{AB0} - Z_{AB}$ the transformers in this case being both the same, equation (**91**) becomes in this particular case where Z_{AB0} is infinite

$$\left.\begin{aligned} S^1 \check{E}_{ab1} &= S^1 \{ (3 Z + 2 Z_{AB})\, \check{I}_{ab} + Z_{AB}\, \check{I}_{ab2} \} \\ S^2\, O &= S^2 \{ Z_{AB}\, \check{I}_{ab1} + (3 Z + 2 Z_{AB})\, \check{I}_{ab2} \} \end{aligned} \right\} \quad (95)$$

and we have

$$\check{I}_{ab0} = - \check{I}_{ab1} - I_{ab2} \quad (96)$$

Similarly, instead of (**94**) we have

$$\left.\begin{aligned} S^1 \check{E}_{ab1} &= S \{ (3 Z_1 + 2 Z_{AB})\, \check{I}_{ab1} + Z_{AB}\, \check{I}_{ab2} \} \\ S^2\, O &= S^2 \{ Z_{AB}\, \check{I}_{ab1} + (3 Z_2 + 2 Z_{AB})\, \check{I}_{ab2} \} \end{aligned} \right\} \quad (97)$$

The secondary voltages are obtained from (**90**) and (**93**) for this latter case.

The solution of (**95**) gives

$$\left.\begin{aligned}
\check{I}_{ab1} &= \frac{3\,Z_1 + 2\,Z_{AB}}{(3\,Z_1 + 3\,Z_{AB})\;(3\,Z_1 + Z_{AB})}\;\check{E}_{ab} \\
\check{I}_{ab2} &= -\;\frac{Z_{AB}}{(3\,Z_1 + 3\,Z_{AB})\;(3\,Z_1 + Z_{AB})}\;\check{E}_{ab} \\
\check{I}_{ab0} &= -\;\frac{1}{3\,Z_1 + 3\,Z_{AB}}\;\check{E}_{ab}
\end{aligned}\right\} \qquad (98)$$

And we have

$$\left.\begin{aligned}
S^1\,\check{I}_{a1} &= S^1\;\frac{3\,Z_1 + 2\,Z_{AB}}{3\,(Z_1 + Z_{AB})\left(Z_1 + \frac{Z_{AB}}{3}\right)}\;\check{E}_a \\
S^2\,\check{I}_{a2} &= S^2\;\frac{Z_{AB}}{3\,(Z_1 + Z_{AB})\left(Z_1 + \frac{Z_{AB}}{3}\right)}\;\check{E}_b
\end{aligned}\right\} \qquad (99)$$

And therefore

$$\left.\begin{aligned}
\check{I}_a &= \frac{\check{E}_a}{Z_1 + \frac{Z_{AB}}{3}} + \frac{\frac{1}{3}\,Z_{ab}}{(Z_1 + Z_{AB})\left(Z_1 + \frac{Z_{AB}}{3}\right)}\check{E}_{ab} \\
\check{I}_b &= \frac{\check{E}_b}{Z_1 + \frac{Z_{AB}}{3}} - \frac{\frac{1}{3}\,Z_{AB}}{(Z_1 + Z_{AB})\left(Z_1 + \frac{Z_{AB}}{3}\right)}\check{E}_{ab} \\
\check{I}_c &= \frac{\check{E}_c}{Z_1 + \frac{Z_{AB}}{3}}
\end{aligned}\right\} \qquad (100)$$

Three Phase System with Symmetrical Waves Having Harmonics

We may express $\check{E}_a$ in the following form:

$$\left.\begin{aligned}
\check{E}_a &= E_1\,e^{jwt} + E_2\,e^{j2wt} + E_3\,e^{j3wt} + \;.\;. \\
&= \Sigma\,E_n\,e^{jnwt}
\end{aligned}\right\} \qquad (101)$$

where E_n is in general a complex number.

If the system is symmetrical three-phase $\check{E}_b$ is obtained by displacing the complete wave by the angle $-\frac{2\pi}{3}$ or

$$\breve{E}_b = e^{-j\frac{2\pi}{3}} E_1 e^{jw\tau} + e^{-j\frac{4\pi}{3}} E_2 e^{j2w\tau} + e^{-j\frac{6\pi}{3}} E_3 e^{j3w\tau} + \ldots$$

$$E_c = e^{j\frac{2\pi}{3}} E_1 e^{jw\tau} + e^{j\frac{4\pi}{3}} E_2 e^{j2w\tau} e^{j\frac{6\pi}{3}} E_3 e^{j3w\tau} + \ldots$$

or since $e^{-j\frac{2\pi}{3}} = a^2$, $e^{j\frac{2\pi}{3}} = a$ etc.

$$\left.\begin{aligned} \breve{E}_a &= E_1 e^{jwt} + E_2 e^{j2wt} + E_3 e^{j3wt} + \ldots \\ \breve{E}_b &= a^2 E_1 e^{jwt} + a E_2 e^{j2wt} + E_3 e^{j3wt} + \ldots \\ \breve{E}_c &= a E_1 e^{jwt} + a^2 E_2 e^{j\tau wt} + E_3 e^{j3wt} + \ldots \end{aligned}\right\} \tag{102}$$

or

$$\left.\begin{aligned} S(\breve{E}_a) = {} & S^0 \{E_3 e^{j3wt} + E_6 e^{j6wt} + E_9 e^{j9wt} + \ldots\} \\ & + S^1 \{E_1 e^{jwt} + E_4 e^{j4wt} + E_7 e^{j7wt} + \ldots\} \\ & + S^2 \{E_2 e^{j2wt} + E_5 e^{j5wt} + E_8 e^{j8wt} + \ldots\} \end{aligned}\right\} \tag{103}$$

$$\begin{aligned} S(\breve{E}_a) = {} & S^0 \Sigma (E_{3n} e^{j3nwt}) + S^1 \Sigma (E_{3n-2} e^{j(3n-2)w\tau}) \\ & + S^2 \Sigma (E_{3n-1} e^{j(3n-1)w\tau}) \end{aligned} \tag{104}$$

This shows that a symmetrical three-phase system having harmonics is made up of positive and negative phase sequence harmonic systems and others of zero phase sequence, that is to say of the same phase in all windings, which comprise the group of third harmonics. These facts are not generally appreciated though they are factors that may have an appreciable influence in the performance of commercial machines. It should be particularly noted that in three phase generators provided with dampers the fifth, eleventh, seventeenth, and twenty-third harmonics produce currents in the damper windings.

In dealing with the complex variable it will be convenient to use for the amplitude the root mean square value for each harmonic. When instantaneous values are required, the real part of the complex variable should be multiplied by $\sqrt{2}$. In the remainder of this paper this convention will be adopted.

Power Presentation in Symmetrical Co-ordinates

Since the power in an alternating current system is also a harmonically varying scalar quantity, it may therefore be represented in the same manner as the current or electromotive force.

that is to say by a complex variable which we shall denote by $(P + j\,Q) + P_H + j\,Q_H)$ $P + j\,Q$ being the mean value, is the term of the complex variable of zero frequency, P representing the real power and Q the wattless power $\sqrt{P^2 + Q^2}$ will be the volt-amperes.

The value of the complex variable $(P + j\,Q) + (P_H + j\,Q_H)$ may be taken as

$$(P + j\,Q) + (P_H + j\,Q_H) = \check{E}\,\hat{I} + \check{E}\,\check{I} \qquad \textbf{(105)}$$

with the provision that for all terms having negative indices the conjugate terms must be substituted, these terms being present in the product $\hat{E}\,\check{I} + \hat{E}\,\hat{I}$, which is the conjugate of the product **(105)**. A similar rule holds good for the symmetrical vector system

$$\left.\begin{aligned} S(\check{E}_a) &= S^0\,\check{E}_{a0} + S^1\,\check{E}_{a1} + \;\ldots\; S^{n-1}\,E_{a(n-1)} \\ S(\check{I}_a) &= S^0\,\check{I}_{a0} + S^1\,\check{I}_{a1} + \;\ldots\; S^{n-1}\,I_{a(n-1)} \end{aligned}\right\} \qquad \textbf{(106)}$$

The conjugate of $S\,\check{I}_a$ is

$$S(\hat{I}_a) = S^0\,\hat{I}_{a0} + S^{(n-1)}\,\hat{I}_{a1} + \;\ldots\; S^1\,\hat{I}_{a(n-1)} \qquad \textbf{(107)}$$

and the Power is represented by

$$(P + P_b) + j\,(Q + Q_b) = \Sigma\,\{S(\check{E}_a)\,S(\hat{I}_a) + S(\check{E}_a)\,S(\check{I}_a)\} \qquad \textbf{(108)}$$

with the same provision for terms having negative indices the sign Σ signifies that all the products in each sequence are added together.

$$\left.\begin{aligned} \Sigma\,\{S(\hat{I}_a)\,S(\check{E}_a)\} = {} & \Sigma\,S^0\,\{\hat{I}_{a0}\,\check{E}_{a0} + \hat{I}_{a1}\,\check{E}_{a1} + \;\ldots \\ & \qquad \hat{I}_{a(n-1)}\,\check{E}_{a(n-1)}\} \\ & + \Sigma\,S^1\,\{\hat{I}_{a0}\,\check{E}_{a1} + \hat{I}_{a1}\,\check{E}_{a2} + \hat{I}_{a2}\,\check{E}_{a3} + \;\ldots \\ & \qquad \hat{I}_{a(n-1)}\,\check{E}_{a0}\} \\ & + \Sigma\,S^2\,\{\hat{I}_{a0}\,\check{E}_{a2} + \hat{I}_{a1}\,\check{E}_{a3} + \hat{I}_{a2}\,\check{E}_{4} + \;\ldots \\ & \qquad \hat{I}_{a(n-1)}\,\check{E}_{a1}\} \\ & \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ & + \Sigma\,S^{(n-1)}\,\{\hat{I}_{a0}\,\check{E}_{a(n-1)} + \hat{I}_{a1}\,\check{E}_{a0} + \;\ldots \\ & \qquad + \hat{I}_{a(n-1)}\,\check{E}_{a(n-2)}\} \end{aligned}\right\} \qquad \textbf{(109)}$$

The terms prefixed by $S^1, S^2, S^3 \quad . \quad . \quad . \quad S^{(n-1)}$ all become zero and since S^0 becomes n

$$\Sigma S(\dot{I}_a) S(\check{E}_a) = n \{\dot{I}_{a0} \check{E}_{a0} + \dot{I}_{a1} \check{E}_{a1} + \quad . \quad . \quad . \quad \dot{I}_{a(n-1)} \check{E}_{a(n-1)}\} \qquad (110)$$

In a similar manner it may be shown that

$$\Sigma S(\check{I}_a) S(\check{E}_a) = n \{\check{I}_{a0} \check{E}_{a0} + \check{I}_{a1} \check{E}_{a(n-1)} + \check{I}_{a2} \check{E}_{a(n-2)} + \quad . \quad . \quad . \quad \check{I}_{a(n-1)} \check{E}_{a1}\} \qquad (111)$$

and therefore

$$(P + jQ) + (P_H + jQ_H) = n \{\dot{I}_{a0} \check{E}_{a0} + \dot{I}_{a1} \check{E}_{a1} + \quad . \quad . \quad . \quad \dot{I}_{a(n-1)} \check{E}_{a(n-1)}\} + n \{\check{I}_{a0} \check{E}_{a0} + \check{I}_{a1} \check{E}_{a(n-1)} + \quad . \quad . \quad . \quad \check{I}_{a(n-1)} \check{E}_{a1}\} \qquad (112)$$

For a three-phase system the expression reduces to

$$(P + jQ) + (P_H + jQ_b) = 3(\dot{I}_{a0} \check{E}_{a0} + \dot{I}_{a1} \check{E}_{a1} + \dot{I}_{a2} \check{E}_{a2}) + 3(\check{I}_{a0} \check{E}_{a0} + \check{I}_{a1} \check{E}_{a2} + \check{I}_{a2} \check{E}_{a1}) \qquad (113)$$

In the above expression $P + P_H$ is the value of the instantaneous power on the system, P being the mean value and P_H the harmonic portion. When the currents are simple sine waves, Q may be interpreted to be the mean wattless power of the circuit or the sum of the wattless voltamperes of each circuit. In rotating machinery since the coefficients of mutual induction may be complex harmonic functions of the angular velocity, this is not strictly true for all cases; but if the effective impedances to the various frequencies of the component currents be used, it will be found to be equal to the mean wattless voltamperes of the system with each harmonic considered independent.

In a balanced polyphase system P_H and Q_H both become zero.

The instantaneous power is a quantity of great importance in polyphase systems because the instantaneous torque is proportional to it and this quantity enters into the problem of vibrations which is at times a matter of great importance, especially when caused by unbalanced e. m. fs. A system of currents and e. m. fs. may be transformed to balanced polyphase by means of transformers alone, provided that the value of P_H is zero, while on the other hand polyphase power cannot be supplied from a pulsating power system without means for

supplying the necessary storage to make a continuous flow of energy.

PART II

Application of the Method to Rotating Polyphase Networks

The methods of determining the constants Z_a Z_u, M, etc., of co-axial cylindrical networks is taken up in Appendix I of this paper. It will be assumed that the reader has familiarized himself with these quantities and understands their significance. We shall first consider the case of symmetrically wound machines taking up the simple cases first and proceeding to more complex ones.

Symmetrically Wound Induction Motor Operating on Unsymmetrical Polyphase Circuit

Denoting the pole pitch angle by π let the synchronous angular velocity be ω_0 and let the angular slip velocity be ω_1. And let $S^1 E_{a1}$ $S^2 E_{a2}$ be the symmetrical components of impressed polyphase e. m. f. Let R_a be the primary resistance and R_u the secondary resistance. The primary self-inductance being M_{aa}, that of the secondary being M_{uu} and corresponding symbols being used to denote the mutual inductances between the different pairs of windings. Then by means of **(39)**, **(40)**, **(56)** and **(57)**

$$\left.\begin{aligned}
S^1 \check{E}_{a}{}^1 &= S^1 \left\{ R_a \check{I}_{a1} + 1\tfrac{1}{2}\, M_{aa} \frac{d}{dt} \check{I}_{a1} \right. \\
&\qquad \left. + 1\tfrac{1}{2}\, M_{au} \frac{d}{dt} e^{j(w_0 - w_1)t} \check{I}_{u1} \right\} \\
S^2 \check{E}_{a2} &= S^2 \left\{ R_a \check{I}_{a2} + 1\tfrac{1}{2}\, M_{aa} \frac{d}{dt} \check{I}_{a2} \right. \\
&\qquad \left. + 1\tfrac{1}{2}\, M_{au} \frac{d}{dt} e^{-j(w_0 - w_1)t} \check{I}_{u2} \right\} \\
S^1 \check{E}_{u1} = O &= S^1 \left\{ R_u \check{I}_{u1} + 1\tfrac{1}{2}\, M_{uu} \frac{d}{dt} \check{I}_{u1} \right. \\
&\qquad \left. + 1\tfrac{1}{2}\, M_{au} \frac{d}{dt} e^{-j(w_0 - w_1)t} \check{I}_{a1} \right\} \\
S^2 \check{E}_{u2} = O &= S^2 \left\{ R_u \check{I}_{u2} + 1\tfrac{1}{2}\, M_{uu} \frac{d}{dt} \check{I}_{u2} \right. \\
&\qquad \left. + 1\tfrac{1}{2}\, M_{au} \frac{d}{dt} e^{j(w_0 - w_1)t} \check{I}_{a2} \right\}
\end{aligned}\right\} \quad \textbf{(114)}$$

denote $1\frac{1}{2}\ M_{aa}$ by L_a and $1\frac{1}{2}\ M_{uu}$ by L_u, $1\frac{1}{2}\ M_{au}$ by M, the equations (**1**) become

$$\left.\begin{aligned}
S^1\,\check{E}_{a1} &= S^1\left\{\left(R_a + L_a\frac{d}{d\,t}\right)\check{I}_{a1} + M\frac{d}{d\,t}\,e^{j(w_0-w_1)t}\,\check{I}_{u1}\right\}\\
S^2\,\check{E}_{a2} &= S^2\left\{\left(R_a + L_a\frac{d}{d\,t}\right)\check{I}_{a2} + M\frac{d}{d\,t}\,e^{-j(w_0-w_1)t}\,\check{I}_{u2}\right\}\\
S^1\,\check{E}_{u1} = O &= S^1\left\{\left(R_u + L_u\frac{d}{d\,t}\right)\check{I}_{u1} + M\frac{d}{d\,t}\,e^{-j(w\ -w_1)t}\,\check{I}_{a1}\right\}\\
S^2\,\check{E}_{u2} = O &= S^2\left\{\left(R_u + L_u\frac{d}{d\,t}\right)\check{I}_{u2} + M\frac{d}{d\,t}\,e^{j(w_0-w_1)t}\,\check{I}_{a2}\right\}
\end{aligned}\right\} \tag{115}$$

From the last two equations we have

$$\check{I}_{u1} = -\frac{M\dfrac{d}{d\,t}}{R_u + L_u\dfrac{d}{d\,t}}\,e^{-j(w_0-w_1)}\,\check{I}_{a1} \tag{116}$$

$$\check{I}_{u2} = -\frac{M\dfrac{d}{d\,t}}{R_u + L_u\dfrac{d}{d\,t}}\,e^{j(w_0-w_1)t}\,\check{I}_{a2} \tag{117}$$

Substituting these in the first two equations of (**115**) we obtain

$$S'\,\check{E}_{a1} = S^1\left[\left(R_a + L_a\frac{d}{d\,t}\right) - \frac{M^2\dfrac{d}{d\,t}\left\{\dfrac{d}{d\,t} - j\,(w_0 - w_1)\right\}}{R_u + L_u\left\{\dfrac{d}{d\,t} - j\,(w_0 - w_1)\right\}}\right]\check{I}_{a1} \tag{118}$$

$$S^2 \check{E}_{a2} = S^2 \left[\left(R_a + L_a \frac{d}{d\,t} \right) - \frac{M^2 \dfrac{d}{d\,t} \left\{ \dfrac{d}{d\,t} + (j\,w_0 - w_1) \right\}}{R_u + L_u \left\{ \dfrac{d}{d\,t} - j\,(w_0 - w_1) \right\}} \right] \check{I}_{a2} \qquad (119)$$

If $\check{E}_{a1} = E_{a1}\, e^{jwt}$ and $\check{E}_{a2} = E_{a2}\, e^{jwt}$ the solution for $\check{I}_{a1}$ and $\check{I}_{a2}$ will be

$$\check{I}_{a1} = \frac{\check{E}_{a1}}{Z_1} \qquad (120)$$

$$\check{I}_{a2} = \frac{\check{E}_{a2}}{Z_2} \qquad (121)$$

Where

$$Z_1 = R_a + j\,w_0\,L_a + \frac{w_0\,w_1\,M^2}{R_u^2 + w_1^2\,L_u^2}\,(R_u - j\,w_1\,L_u) \qquad (122)$$

$$Z_2 = R_a + j\,w_0\,L_a + \frac{w_0\,(2\,w_0 - w_1)\,M^2}{R_u^2 + (2\,w_0 - w_1)^2\,L_u^2}\,\{R_u - j\,(2\,w_0 - w_2)\,L_u\} \qquad (123)$$

The impedances Z_1 and Z_2 will be found more convenient to use in the form

$$Z_1 = (R_a + K_1^2\,R_u) + j\,w_0\,(L_a - K_1^2\,L_u) + \frac{w_0 - w_1}{w_1}\,K_1^2\,R_u \qquad (124)$$

$$Z_2 = (R_a + K_2^2\,R_u) + j\,w_0\,(L_a - K_2^2\,L_u) - \frac{w_0 - w_1}{Z\,w_0 - w_1}\,K_2^2\,R_u \qquad (125)$$

Where, as we will see later, K_1^2 and K_2^2 are the squares of the transformation ratios between primary and secondary currents of positive and negative phase sequence.

The last real term in each expression is the virtual resistance due to mechanical rotation and when combined with the mean square current represents mechanical work performed, the positive sign representing work performed and the negative sign work required.

Thus, for example, to enable the currents $S^2\,\check{I}_{a2}$ to flow, the mechanical work $3\,I_{a2}^2\,\dfrac{w_0 - w_1}{2\,w_0 - w_1}\,K_1^2\,R_u$ must be applied to the shaft of the motor.

The phase angles of the symmetrical systems $S^1 \check{I}_{a1}$ $S^2 \check{I}_{a2}$ with respect to their impressed e. m. f., $S^1 \check{E}_{a1}$ and $S^2 \check{E}_{a2}$ are given by these impedances so that the complete solution of the primary circuit is thus obtained.

The secondary currents are given by equations (**116**) and (**117**) and are

$$\check{I}_{u1} = - \frac{j\, w_1\, M}{R_u + j\, w_1\, L_u}\, I_{a1}\, e^{j w_1 T} = \check{K}_1\, I_{a1} e^{j w_1 T} \qquad (\mathbf{126})$$

$$\check{I}_{u2} = - \frac{j\, (2\, w_0 - w_1)\, M}{R_u + j\, (2\, w_0 - w_1)\, L_u}\, I_{a2}\, e^{j(2 w_0 - w_1) T} = \check{K}_2\, I_{a2}\, e^{j(2 w_0 - w_1) T} \qquad (\mathbf{127})$$

In the results just given, M is not the maximum value of mutual inductance between a pair of primary and secondary windings but is equal to the total mutual inductance due to a current passing through the two coils W and V through the coil

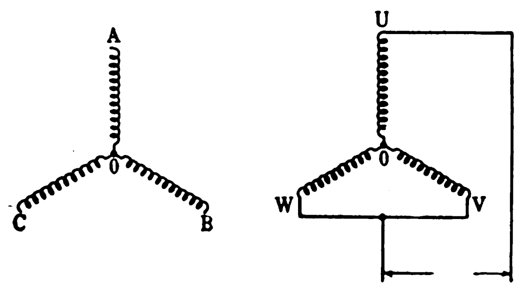

FIG. 5

U as shown in the sketch Fig 5 and the winding "A" when A and U have their planes of symmetry coincident.

Where the windings are symmetrical the induced e. m. f. is independent of the division of current between W and V, but this quantity must not be used in unsymmetrical windings, or with star windings having a neutral point connection so that $\check{I}_{a0}$ is not zero.

The appearance of M in this equation follows from the equation

$$\check{I}_u + \check{I}_v + \check{I}_w = 0$$

so that

$$\check{I}_u = - (\check{I}_v + \check{I}_w)$$

The power delivered by the motor is

$$P_o = 3 \left\{ \frac{w_0 - w_1}{w_1} K_1^2\, I_{a1}^2\, R_u - \frac{w_0 - w_1}{2\, w_0 - w_1} K_2^2\, I_{a2}^2\, R_u \right\} \qquad (\mathbf{128})$$

The copper losses are given by

$$P_L = 3\,\{I_{a1}^2\,(R_p + K_1^2\,R_u) + I_{a2}^2\,(R_p + K_2^2\,R_u)\} \qquad \textbf{(129)}$$

The iron loss is independent of the copper loss and power output. The iron loss and windage may be taken as

$$P_F = \text{Iron loss and windage} \qquad \textbf{(130)}$$

The power input as

$$P_I = P_O + P_L + P_F \qquad \textbf{(131)}$$

The mechanical power output is P_O less friction and windage losses.

$$\text{Torque} = 3\left\{\frac{1}{w_1}\,K_1^2\,I_{a1}^2\,R_u - \frac{1}{2\,w_0 - w_1}\,K_2^2\,I_{a2}^2\,R_u\right\} \times 10^7 \text{ dyne-cm.} \qquad \textbf{(132)}$$

The kv-a. at the terminals is

$$\sqrt{P_I^2 + Q_I^2} = \text{The effective value of } 3\,(E_{a1}\,I_{a1} + E_{a2}\,I_{a2}) \qquad \textbf{(133)}$$

This last result may be arrived at in the following way

$$\left.\begin{aligned} S\,(\check{E}_a) &= S^1\,\check{E}_{a1} + S^2\,\check{E}_{a2}) \\ S\,(\hat{I}_a) &= S^2\,\hat{I}_{a1} + S^1\,\hat{I}_{a2} \end{aligned}\right\} \qquad \textbf{(134)}$$

Since $S^2\hat{I}_{a1}$ is conjugate to $S^1\,\check{I}_{a1}$, etc.

The product of $\check{E}_{s1}$ and $\hat{I}_{sa}$ is the power product of the two vectors, $S\,(\check{E}_a)$ and $S\,(\check{I}_a)$ and omits the harmonic variation as a double frequency quantity, the average wattless appears as an imaginary non-harmonic quantity.

$$P_I + j\,Q_I\,\Sigma\,(S^0\,\check{E}_{a1}\,\hat{I}_{a1} + S^0\,\check{E}_{a2}\,\hat{I}_{a2} + S^1\,\check{E}_{a2}\,\hat{I}_{a1} + S^2\,\check{E}_{a1}\,\hat{I}_{a2}) \qquad \textbf{(135)}$$

The S^1 and S^2 products have zero values, since the sum of the terms of each sequence is zero, hence—

$$P_I + j\,Q_I = 3\,(\check{E}_{a1}\,\hat{I}_{a1} + \check{E}_{a2}\,\hat{I}_{a2}) \qquad \textbf{(136)}$$

$$\sqrt{P_I^2 + Q_I^2} = \text{The effective value of } 3\,(\check{E}_{a1}\,\hat{I}_{a1} + \check{E}_{a2}\,\hat{I}_{a2}) \qquad \textbf{(137)}$$

The solution for the general case of symmetrical motor operating on an unsymmetrical circuit is not of as much interest as

certain special cases depending thereon. Some of the most important of these will be taken up in the following paragraphs.

Case I. Single-Phase e. m. f. Impressed across one phase of three-phase motor.

Assuming the single-phase voltage to be $\breve{E}_{bc}$ impressed across the terminals B C. The known data or constraints are

$$\left.\begin{aligned} \breve{E}_{bc} &= j\sqrt{3}\,(\breve{E}_{a1} - \breve{E}_{a2}) \\ \breve{I}_a &= 0,\ \breve{I}_b = -\breve{I}_c \end{aligned}\right\} \tag{138}$$

and therefore

$$\breve{I}_{a1} = -\breve{I}_{a2} \tag{139}$$

$$\frac{\breve{E}_{a1}}{Z_1} = -\frac{\breve{E}_{a2}}{Z_2}$$

$$\breve{E}_{a2} = -\frac{Z_2}{Z_1}\breve{E}_{a1} \tag{140}$$

Substituting in (**138**)

$$\left.\begin{aligned} \breve{E}_{a1} &= -j\frac{\breve{E}_{bc}}{\sqrt{3}} \cdot \frac{Z_1}{Z_1 + Z_2} \\ \breve{E}_{a2} &= j\frac{\breve{E}_{bc}}{\sqrt{3}} \cdot \frac{Z_2}{Z_1 + Z_2} \end{aligned}\right\} \tag{141}$$

and therefore

$$\left.\begin{aligned} \breve{I}_{a1} &= -j\frac{\breve{E}_{bc}}{\sqrt{3}} \cdot \frac{1}{Z_1 + Z_2} \\ \breve{I}_{a2} &= j\frac{\breve{E}_{bc}}{\sqrt{3}} \cdot \frac{1}{Z_1 + Z_2} \end{aligned}\right\} \tag{142}$$

Since $\breve{I}_b = \breve{I}_{b1} + \breve{I}_{b2} = a^2\,\breve{I}_{a1} + a\,\breve{I}_{a2}$

$$\breve{I}_b = -I_c = -\frac{\breve{E}_{bc}}{Z_1 + Z_2} \tag{143}$$

$$P_0 = \left(\frac{w_0 - w_1}{w_1} K_2^2 R_u - \frac{w_0 - w_1}{2\,w_0 - w_1} K_2^2 R_u\right) I_0^2 \tag{144}$$

$$P_1 + j\,Q_1 = I_b^2\,(Z_1 + Z_2) + P_F \tag{145}$$

The power factor is obtained from (**145**) by the formula

$$\cos\alpha = \frac{P_1}{\sqrt{P_1^2 + Q_1^2}} \tag{146}$$

Substituting from (**142**) in equation (**126**) and (**127**) of the general case we obtain for the secondary currents

$$\left.\begin{aligned} \check{I}_{u1} &= -j\,\check{K}_1 \frac{E_{bc}}{Z_1 + Z_2}\, \epsilon^{j w_1 t} \\ \check{I}_{u2} &= j\,\check{K}_2 \frac{E_{bc}}{Z_1 + Z_2}\, \epsilon^{j(2w_0 - w_1)t} \end{aligned}\right\} \quad (\mathbf{147})$$

Many unsymmetrical cases may be expressed in terms of the operation of coupled symmetrical motors operating on symmetrical systems. This is invariably the case with symmetrical polyphase motors operating on single phase circuits. Since the physical interpretations are useful in impressing the facts on ones memory they will be given whenever they appear to be useful.

Equations (**141**) and (**142**) show that single-phase operation is exactly equivalent to operating two duplicate motors in series with a symmetrical polyphase e. m. f. $S^1 E_{ab}$ impressed across one motor, the other being connected in series with the first but with phase sequence reversed, the two motors being directly coupled.

Case II. B and C connected together e. m. f. impressed across A B.

The data given by the conditions of constraint are

$$\left.\begin{aligned} \check{E}_{ab} &= -\check{E}_{ca} \\ \check{E}_{bc} &= O = j\sqrt{3}\,(\check{E}_{a1} - \check{E}_{a2}) \end{aligned}\right\} \quad (\mathbf{148})$$

We therefore have

$$\check{E}_{a1} = \check{E}_{a2} = -\frac{\check{E}_{ab}}{3} \quad (\mathbf{149})$$

and

$$\left.\begin{aligned} \check{I}_{a1} &= -\frac{\check{E}_{ab}}{3\,Z_1} \\ \check{I}_{a2} &= -\frac{\check{E}_{ab}}{3\,Z_2} \end{aligned}\right\} \quad (\mathbf{150})$$

The remainder follows from the general solution and need not be repeated here.

(**150**) shows that a motor operated in this manner is the exact equivalent in all respects to two duplicate mechanically coupled polyphase motors, one of which has sequence reversed, operating in parallel on a balanced three-phase circuit of e. m. f. $S^1 \dfrac{E_{ab}}{\sqrt{3}}$.

The secondary currents follow from substitution of (**150**) in equations (**126**) and (**127**) of the general case.

Case III. B and C connected together by the terminals of a balance coil, the impressed e. m. f. E_{AD} *applied between A and the middle point of the balance coil. Resistance and reactance of balance coil negligible.*

The data furnished by the connection in this case is

$$\check{I}_b = \check{I}_c = -\frac{\check{I}_a}{2} \qquad (\mathbf{151})$$

and therefore

$$\check{I}_{a1} = \frac{\check{I}_a - a\dfrac{\check{I}_a}{2} - a^2\dfrac{\check{I}_a}{2}}{3} = \frac{\check{I}_a}{2}$$

$$\check{I}_{a2} = \check{I}_{a1} = \frac{\check{I}_a}{2}$$

We therefore have

$$\left.\begin{aligned} \check{E}_{a1} &= \frac{Z_1\,\check{I}_a}{2} \\ \check{E}_{a2} &= \frac{Z_2\,\check{I}_a}{2} \end{aligned}\right\} \qquad (\mathbf{152})$$

we have

$$\begin{aligned} \check{E}_{ab} &= j\sqrt{3}\,(a\,\check{E}_{a1} - a^2\,\check{E}_{a2}) \\ &= j\sqrt{3}\,\frac{\check{I}_a}{2}\,(a\,Z_1 - a^2\,Z_2) \end{aligned}$$

$$\check{E}_{bc} = j\sqrt{3}\,\frac{\check{I}_a}{2}\,(Z_1 - Z_2)$$

$$\left.\begin{aligned} \check{E}_{ad} &= \left(\check{E}_{ab} + \frac{\check{E}_{bc}}{2}\right) \\ &= j\sqrt{3}\,\frac{\check{I}_a}{2}\,\{(a + \tfrac{1}{2})\,Z_1 - (a^2 + \tfrac{1}{2})\,Z_2\} \\ &= -\tfrac{3}{4}\,\check{I}_a\,(Z_1 + Z_2) \end{aligned}\right\} \qquad (\mathbf{153})$$

and therefore,

$$\check{I}_a = -1\tfrac{1}{3}\,\frac{\check{E}_{ad}}{Z_1 + Z_2} \qquad (\mathbf{154})$$

$$P_0 = \frac{3}{4}\left\{\frac{w_0 - w_1}{w_1} K_1^2 - \frac{w_0 - w_1}{2\,w_0 - w_1} K_2^2\right\} I_a^2 R_a \qquad (155)$$

$$P_1 + j\,Q_1 = \frac{3}{4} I_a^2 (Z_1 + Z_2) + P_v \qquad (156)$$

$$\cos\alpha = \frac{P_1}{\sqrt{P_1^2 + Q_1^2}} \qquad (157)$$

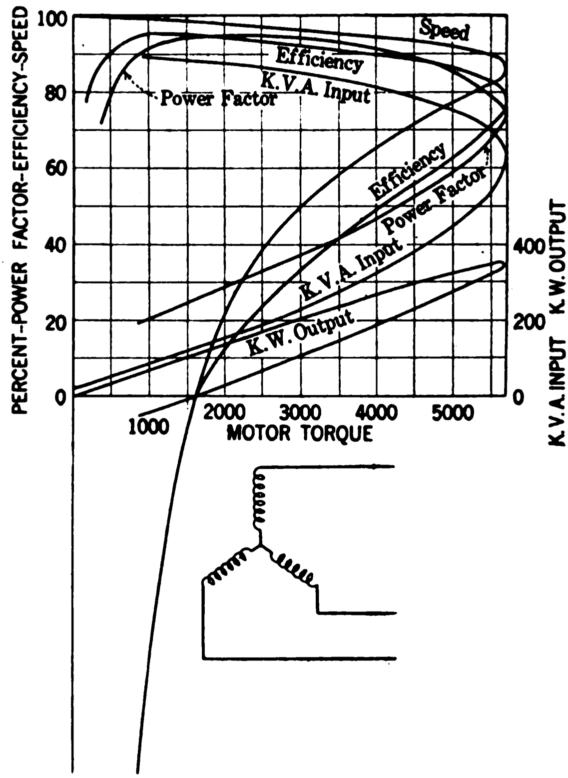

FIG. 6—CHARACTERISTICS OF THREE-PHASE INDUCTION MOTOR—BALANCED THREE-PHASE

Evidently (155), (156) and (157) are identical to (144), (145) and (146) if I_a is equal to $I_b \div \frac{\sqrt{3}}{2}$. This will be the case if the value of $E_{ad} = \frac{\sqrt{3}}{2}$ times that of E_{bc}. The total heating of

the motors will be the same in each case but the heating in one phase for Case III will be one-third greater than for Case I.

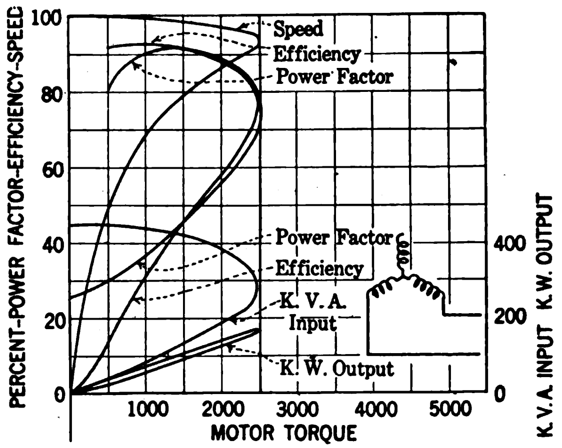

FIG. 7—CHARACTERISTICS OF THREE-PHASE INDUCTION MOTOR—SINGLE-PHASE OPERATION —ONE LEAD OPEN

This method of operation is therefore, as far as total losses, etc. are concerned, the exact counterpart of two polyphase

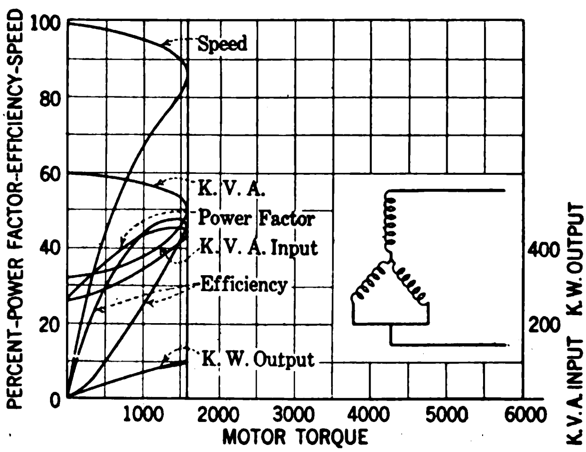

FIG. 8—CHARACTERISTICS OF THREE-PHASE INDUCTION MOTOR—SINGLE-PHASE OPERATION

motors connected in series with shafts mechanically connected, one of which has its phase sequence reversed.

Figs. 6, 7 and 8 show characteristic curves of a three-phase

induction motor operating respectively on a symmetrical circuit, according to Case I and according to Case II.

Synchronous Machinery

The Symmetrical Three-Phase Generator Operating on Unsymmetrically Loaded Circuit

The polyphase salient pole generator is not strictly a symmetrical machine, the exciting winding is not a symmetrical polyphase winding and it therefore sets up unsymmetrical trains of harmonics in exactly the same way as they are set up in an induction motor with unsymmetrical secondary winding. These cases will therefore be taken up later on. A three-phase generator may however be wound with a distributed polyphase winding to serve both as exciting and damper winding and if properly connected will be perfectly symmetrical.' Such a machine will differ from an induction motor only in respect to the fact that it operates in synchronism and has internally generated symmetrical e. m. fs. which we will denote by $S^1 \check{E}_{a1}$, $S^2 \check{E}_{a2}$ the negative phase sequence component being zero; an e. m. f. $S^0 \check{E}_{a0}$ may exist but since in all the connections that will be considered there will be no neutral connection its value may be ignored. If the load impedances be Z_a', Z_b' and Z_c' they may be expressed by

$$Z_{sa}^1 = S^0 Z_{a0}^1 + S^1 Z_{a1}' + S^2 Z_{a2}'$$

and the equations of the generator will be

$$\left.\begin{aligned}
S^1 \check{E}_{a1} &= S^1 \left\{ \left(R_a + L_a \frac{d}{dt}\right) \check{I}_{a1}' + Z_{a0}' I_{a1}' \right. \\
&\qquad \left. + Z_{a2}' I_{a2}' + M \frac{d}{dt} e^{ju\omega t} \check{I}_{u1}' \right\} \\
O &= S^2 \left\{ \left(R_a + L_a \frac{d}{dt}\right) \check{I}_{a2}' + Z_{a0}' I_{a2}' \right. \\
&\qquad \left. + Z_{a1}^1 \check{I}_{a1}' + M \frac{d}{dt} e^{-ju\omega t} \check{I}_{u2}' \right\} \\
O &= \left(R_u + L_u \frac{d}{dt}\right) \check{I}_{u1}' + M \frac{d}{dt} e^{-ju\omega t} \check{I}_{a1}' \\
O &= \left(R_u + L_u \frac{d}{dt}\right) \check{I}_{u2}' + M \frac{d}{dt} e^{ju\omega t} \check{I}_{a2}'
\end{aligned}\right\} \quad (158)$$

The last two equations give

$$\left.\begin{aligned} I_{u1}' &= -\frac{M\dfrac{d}{dt}}{R_u + L_u\dfrac{d}{dt}}\, e^{-jw_0 t}\, \check{I}_{a1}' \\ I_{u2}' &= -\frac{M\dfrac{d}{dt}}{R_u + L_u\dfrac{d}{dt}}\, e^{jw_0 t}\, I_{a2}' \end{aligned}\right\} \qquad \textbf{(159)}$$

which on substitution in the first two equations of (**158**) give the equations

$$\left.\begin{aligned} &\left\{ R_a + L_a\frac{d}{dt} - \frac{M^2\dfrac{d}{dt}\left(\dfrac{d}{dt} - jw_0\right)}{R_u + L_u\left(\dfrac{d}{dt} - jw_0\right)} \right\} \check{I}_{a1}' \\ &\qquad\qquad + Z_{a0}^1\, \check{I}_{a1}' + Z_{a2}'\, \check{I}_{a2}' = \check{E}_{a1} \\ &Z_{a1}^1\, \check{I}_{a1}' + \left\{ R_a + L_a\frac{d}{dt} \right. \\ &\left. - \frac{M^2\dfrac{d}{dt}\left(\dfrac{d}{dt} + jw_0\right)}{R_u + L_u\left(\dfrac{d}{dt} + jw_0\right)} \right\} \check{I}_{a2}' + Z_{a0}^1\, \check{I}_{a2}' = 0 \end{aligned}\right\} \qquad \textbf{(160)}$$

or if

$$\check{E}_{a1} = E_{a1}\, e^{jw_0 t} \qquad \textbf{(161)}$$

the impedances Z_{a0}, Z_{a1}, Z_{a2} become ordinary impedance for an electrical angular velocity w_0 and equations (**160**) become

$$\left.\begin{aligned} &(R_a + j w L_a + Z_{a0}^1)\, \check{I}_{a1}' + Z_{a2}'\, \check{I}_{a\,2}' = \check{E}_{a1} \\ &Z_{a1}'\, \check{I}_{a1}' + \{Z_{a0}' + (R_a + K_2^2 R_u) + j\, 2\, w_0\, (L_a - K_2^2 L_u) \\ &\qquad\qquad - \tfrac{1}{2} K_2^2 R_u\}\, \check{I}_{a2}' = 0 \end{aligned}\right\} \qquad \textbf{(162)}$$

It is apparent that in the generator the impedances

$$R_a + j\, w_0\, L_a = Z_1'$$

and $\{(R_a + K_2^2 R_u) + j\, 2\, w_0\, (L_a - K_2^2 L_u) - \tfrac{1}{2} K^2 R_u\} = Z_2'$

take the place of Z_1 and Z_2 in the symmetrical induction motor operating on an unsymmetrical circuit, and we may express equation (**162**)

$$\left.\begin{aligned} (Z_{a0}' + Z_1')\, \check{I}_{a1}' + Z_{a2}'\, \check{I}_{a2}' &= \check{E}_{a1} \\ Z_a'\, \check{I}_{a1}' + (Z_{a0}' + Z_2')\, I_{a2}' &= O \end{aligned}\right\} \quad (\mathbf{163})$$

which gives

$$\check{I}_{a2}' = - \frac{Z_{a1}'}{Z_{a0} + Z_2'}\, I_{a1}'$$

$$\check{I}_{a1}' = \frac{\check{E}_{a1}}{(Z_{a0}' + Z_1') - \dfrac{Z_{a1}'\, Z_{a2}'}{Z_{a0}' + Z_2'}}$$

Or in more symmetrical form

$$\left.\begin{aligned} \check{I}_{a1}' &= \frac{Z_{a0}' + Z_2'}{(Z_{a0}' + Z_1')\,(Z_{a0}' + Z_2') - Z_{a1}'\, Z_{a2}'}\, \check{E}_{a1} \\ \check{I}_{a2}' &= - \frac{Z_{a1}^1}{(Z_{a0}' + Z_1')\,(Z_{a0}' + Z_2') - Z_{a1}'\, Z_{a2}'}\, \check{E}_{a1} \end{aligned}\right\} \quad (\mathbf{164})$$

From (**159**) we have for the damper currents

$$\left.\begin{aligned} \check{I}_{u1}' &= O \text{ if } R_u > O \\ \check{I}_{u2}' &= - \check{K}_2\, I_{a2}\, e^{j\,2u\,\omega t} \\ &\text{where } \check{K}_2 = j\, \frac{2\, w_0\, M}{R_u + j\, 2\, w_0\, L_u} \end{aligned}\right\} \quad (\mathbf{165})$$

A particular case of interest is when the load is a Synchronous Motor or Induction Motor with unsymmetrical line impedances in series—Equation (**163**) becomes

$$\left.\begin{aligned} (Z_{a0}' + Z_1' + Z_1)\, \check{I}_{a1}' + Z_{a2}'\, I_{a2}' &= \check{E}_{a2} \\ Z_{a1}\, \check{I}_{a1}' + (Z_{a0}' + Z_2' + Z_2)\, I_{a2}' &= O \\ I_{a1}^1 &= \frac{Z_{a0}' + Z_2' + Z_2}{(Z_{a0}'+Z_1'+Z_1)\;(Z_{a0}'+Z_2'+Z_2) - Z_{a1}\, Z_{a2}}\, \check{E}_{a1} \\ I_{a2}^1 &= \frac{Z_{a1}}{(Z_{a0}'+Z_1'+Z_1)\;(Z_{a0}'+Z_2'\; Z_2) - Z_{a1}\, Z_{a2}}\, \check{E}_{a1} \end{aligned}\right\} \quad (\mathbf{166})$$

An important case is that of a generator feeding into a symmetrical motor and an unsymmetrical load. Let the motor currents be

$\check{I}_a$, $\check{I}_b$, $\check{I}_c$, those of the load I_a', I_b', I_c' and the load impedances Z_a', Z_b', Z_c'. The equations of this system will be

$$\left.\begin{aligned} S^1\,\check{E}_{a1} &= S^1\,\{Z_1'(\check{I}_{a1} + \check{I}_{a1}') + Z_{a0}'\,\check{I}_{a1}' + Z_{a2}'\,\check{I}_{a2}'\} \\ S^1\,\check{E}_{a1} &= S^1\,\{Z_1'(\check{I}_{a1} + \check{I}_{a1}') + Z_1\,\check{I}_{a1}\} \\ S^2\,O &= S^2\,\{Z_2'(\check{I}_{a2} + \check{I}_{a2}') + Z_{a0}'\,\check{I}_{a2} + Z_{a1}'\,\check{I}_{a1}'\} \\ S^2\,O &= S^2\,\{Z_2'(\check{I}_{a2} + \check{I}_{a2}') + Z_2\,\check{I}_{a2}\} \end{aligned}\right\} \quad (167)$$

Or, omitting the sequence symbols and re-arranging—

$$\left.\begin{aligned} \check{E}_{a1} &= Z_1'\,\check{I}_{a1} + (Z_1' + Z_{a0}')\,\check{I}_{a1}' + Z_{a2}'\,\check{I}_{a2}^1 \\ \check{E}_{a1} &= (Z_1' + Z_1)\,\check{I}_{a1} + Z_1'\,\check{I}_{a1}^1 \\ O &= Z_2'\,\check{I}_{a2} + Z_{a1}'\,\check{I}_{a1}^1 + (Z_2' + Z_{a0}')\,\check{I}_{a2}' \\ O &= (Z_2' + Z_2)\,\check{I}_{a2} + Z_2'\,\check{I}_{a2}' \end{aligned}\right\} \quad (168)$$

These equations can be further simplified as follows:

$$\left.\begin{aligned} O &= (Z_2' + Z_2)\,\check{I}_{a2} + Z_2'\,\check{I}_{a2}' \\ O &= -\,Z_2\,\check{I}_{a2} + Z_{a1}'\,\check{I}_{a1}' + Z_{a0}'\,\check{I}_{a2}' \\ O &= -\,Z_1\,\check{I}_{a1} + Z_{a0}'\,\check{I}_{a0}' + Z_{a2}'\,I_{a2}' \\ \check{E}_{a1} &= (Z_1' + Z_1)\,\check{I}_{a1} + Z_1'\,\check{I}_{a1}' \end{aligned}\right\} \quad (169)$$

A set of simultaneous equations which may be easily solved.

THE SINGLE-PHASE GENERATOR IS AN IMPORTANT CASE OF THE THREE-PHASE GENERATOR OPERATED ON AN UNBALANCED LOAD

Let the impedance of the single-phase load be Z and let us suppose it to be made up of three star connected impedances

$$Z_a' = 3\,Z_x + \frac{Z}{2}$$

$$Z_b' = \frac{Z}{2}$$

$$Z_c' = \frac{Z}{2}$$

the value of Z_x in the limit being infinity. Then we have

$$\left.\begin{aligned} Z_{a0}' &= Z_x + \frac{Z}{2} \\ Z_{a1}' &= Z_x \\ Z_{a2}' &= Z_x \end{aligned}\right\} \qquad (\mathbf{170})$$

Equation (**164**) in the limit when Z_x becomes infinite reduces to

$$\begin{aligned} \check{I}_{a1}' &= \frac{\check{E}_{a1}}{Z + Z_1' + Z_2'} \\ \check{I}_{a2} &= -\frac{\check{E}_{a1}}{Z + Z_1' + Z_2'} \end{aligned} \qquad (\mathbf{171})$$

The single-phase load being across the phase $B\ C$, the single-phase current I will therefore be equal to $\check{I}_c$ or

$$\left.\begin{aligned} \check{I} &= \frac{j\sqrt{3}\,\check{E}_{a1}}{Z + Z_1' + Z_2'} \\ &= \frac{\check{E}_{bc}}{Z + Z_1' + Z_2'} \end{aligned}\right\} \qquad (\mathbf{172})$$

$$\left.\begin{aligned} \check{I}_{u1} &= O \text{ if } R_u > O \\ \check{I}_{u2} &= -j\frac{1}{\sqrt{3}}\check{K}_2\,\check{I}\,e^{ju\omega t} \\ \check{I}_{u2} &= -\frac{j\,\check{K}_2}{\sqrt{3}}\,I\,e^{ju\omega t} \end{aligned}\right\} \qquad (\mathbf{173})$$

$\check{I}_{u2}$ is double normal frequency

$$\left.\begin{aligned} P_I + j\,Q_I &= 3\,I^2\,Z \\ P_L + j\,Q_L &= 3\,I^2\,(Z_1' + Z_2') \\ (P + j\,Q) + (P_H + j\,Q_H) &= 3\,\check{E}_{bc}\,(\hat{I} + \check{I}) \end{aligned}\right\} \qquad (\mathbf{174})$$

In the case of the generally unbalanced three-phase load

$$\left.\begin{aligned} P_I + j\,Q_I &= 3\,\{(I_{a1}^2 + I_{a2}^2)\,Z_{a0}' \\ &\qquad + \check{I}_{a1}\,\hat{I}_{a2}\,Z_{a2}' + \hat{I}_{a1}\,\check{I}_{a2}\,Z_{a1}'\} \\ P_L + j\,Q_L &= 3\,\{I_{a1}^2\,Z_1' + I_{a2}^2\,Z_2'\} \\ (P + j\,Q)\,j\,(P_H + j\,Q_H) &= 3\,\check{E}_{a1}\,(\check{I}_{a2} + \hat{I}_{a2}) \end{aligned}\right| \qquad (\mathbf{175})$$

When the generator has harmonics in its wave form equations (**162**) must be written

$$\left.\begin{aligned}
&(R_a + j\,w\,L_a + Z_{a0}')\,\check{I}_{a1}' + Z_{a2}'\,I_{a2}' = \check{E}_{a1} \\
&\quad Z_{a1}'\,I_{a1}' + \{Z_{a0}' + (R_a + K_2^2\,R_u) \\
&\qquad\qquad + j\,2\,w\,(L_a - K_2^2\,L_u) - \tfrac{1}{2}\,a^2\,R_u\}\,I_{a2}' = \check{E}_{a2}
\end{aligned}\right\} \quad (\mathbf{176})$$

Where $\check{E}_{a1}$ is finite, $\check{E}_{a2}$ is zero and vice versa, the frequencies being different in each case, we have therefore a solution for each frequency depending on the phase and amplitude and phase sequence of the e. m. f. of this frequency generated. Of course the values of Z_1' and Z_2' change with each frequency on account of the change in the reactance with frequency, and a value must be taken for w conforming with the frequency of the harmonic under consideration.

Symmetrical Synchronous Motor, Synchronous Condenser, Etc.

As in the case of the generator, the synchronous motor has two impedances, one to the positive phase sequence current of a given frequency and the other to the negative phase sequence current of the same frequency. But, since there is no quantity in the positive phase sequence impedance corresponding to the virtual resistance which indicates mechanical work in an induction motor, its equivalent is furnished by the excitation of the field. Let us denote the e. m. f. due to the field excitation by $S^1\,\check{E}_{a1}'$ assuming it to be for the present a simple harmonic three-phase system. Let P_0 be the output of the motor which will include the windage and iron losses assumed to be constant. Then for the synchronous motor on a balanced circuit of e. m. f. $S^1\,\check{E}_{a1}$ we have

$$S^1\,\check{E}_{a1} = S^1\,\{\check{I}_{a1}\,(R_a' + j\,w\,L_a') + \check{E}_{a1}'\} \quad (\mathbf{177})$$

$$S^0\,\check{E}_{a1}\,\hat{I}_{a1} = S^0\left\{I_{a1}^2\,(R_a' + j\,w\,L_a') + \frac{P_0}{3} - j\,\frac{Q_0}{3}\right\} \quad (\mathbf{178})$$

Where Q_0 is the imaginary part of the product, $\check{E}_{a1}'\,\hat{I}_{a1}$. (**178**) reduces to

$$E_{a1}\,I_{a1}\cos\alpha = I_{a1}^2\,R_a^1 + \frac{P_0}{3} \quad (\mathbf{179})$$

Where $\cos\alpha$ is the required operating power factor. Solving for I_{a1}

$$I_{a1} = \frac{E_{a1} \cos \alpha}{2 R_a^1} \left\{ 1 \pm \sqrt{1 - \frac{4 R_a' P_0}{3 E_{a1}^2 \cos^2 \alpha}} \right\} \tag{180}$$

$$\check{I}_{a1} = \check{E}_{a1} \frac{\cos \alpha}{2 R_{a1}} \left\{ 1 \pm \sqrt{1 - \frac{4 R_{a1}' P_0}{3 E_{a1}^2 \cos^2 \alpha}} \right\} (\cos \alpha - j \sin \alpha) \tag{181}$$

The apparent impedance of the motor is

$$\frac{2 R_1 \sec \alpha}{1 \pm \sqrt{1 - \frac{4 P_0}{3 E_a^2 \cos^2 \alpha}}} (\cos \alpha + j \sin \alpha) \tag{182}$$

and

$$\check{E}_{a1}^1 = \check{E}_{a1} \left[1 - \frac{\cos \alpha}{2 R_a^1} \left\{ 1 \pm \sqrt{1 - \frac{4 R_a' P_0}{3 E_{a1}^2 \cos^2 \alpha}} \right\} (\cos \alpha - j \sin \alpha) (R_a' + j w L_a') \right] \tag{183}$$

The same equations apply to the case of the synchronous condenser with the difference that the mechanical work is that required to overcome the iron and windage losses only.

If we take

$$\left. \begin{aligned} \check{E}_{a1} &= E_{a1} (\cos \alpha + j \sin \alpha) \, e^{jwt} = (A_1 + j B_1) \, e^{jwt} \\ \check{E}_{a1}' &= (A_1' + j B_1') \, e^{jwt} \end{aligned} \right\} \tag{184}$$

we have

$$\check{I}_{a1} = \frac{A_1}{2 R_a^1} \left(1 \pm \sqrt{1 - \frac{4 R_a' P_0}{3 A_1^2}} \right) e^{jwt} \tag{185}$$

$$A_1' = \frac{A_1}{2} \left(1 \pm \sqrt{1 - \frac{4 R_a' P_0}{3 A_1^2}} \right) e^{jwt} \tag{186}$$

$$B_1' = \left\{ R_1' - \frac{j w L_a' A_1}{2 R_a'} \left(1 \pm \sqrt{1 - \frac{4 R_a' P_0}{3 A_1^2}} \right) \right\} e^{jwt} \tag{187}$$

Since α may be a positive or negative angle, the sine may be positive or negative for a positive cosine, and therefore the power factor will be leading or lagging accordingly as B_1 is negative or positive respectively. The double signs throughout are due to the fact that for any given load and power factor there are always two theoretically possible running conditions. However, since

we are concerned only with that one which will give the max. operating efficiency, that is the condition that gives I_{a1} the lesser value, for a given value of P_0 the equations may be written

$$\left.\begin{aligned} \check{I}_{a1} &= \frac{A_1}{2\,R_a^1}\left(1 - \sqrt{1 - \frac{4\,R_a'\,P_0}{3\,A_1^2}}\right) e^{j w_0 t} \\ A_1' &= \frac{A_1}{2}\left(1 + \sqrt{1 - \frac{4\,R_a'\,P_0}{3\,A_1^2}}\right) e^{j w_0 t} \\ B_1' &= \left\{ B_1 - \frac{j\,w_0\,L_a'\,A_1}{2\,R_a'}\left(1 - \sqrt{1 - \frac{4\,R_a'\,P_0}{3\,A_1^2}}\right)\right\} \end{aligned}\right\} \quad (188)$$

And corresponding values for (**180**), (**181**), (**182**) and (**183**) may be obtained by omitting the positive sign in these equations.

Another condition of operation is obtained by inspection of (**180**), due to the fact that I_{a1} must be a real quantity

$$\frac{4\ R_a'\ P_0}{3\ E_{a1}^2\cos^2\alpha} \text{ must be} > 1 \quad (189)$$

this is the condition of stability. In terms of (**184**) it becomes

$$\frac{4\,R_a'\,P_0}{3\,A_1^2} \text{ must be} > 1 \quad (190)$$

The same conditions apply to the synchronous condenser, the total mechanical load in this case being the iron loss and windage and friction losses.

Proceeding now to operation with unbalanced circuits having sine waves the motor also having a sine wave. In addition to equation (**177**) we shall have

$$S^2\,\check{E}_{a2} = S^2\,Z_2'\,\check{I}_{a2} \quad (191)$$

The mechanical power delivered through the operation of this negative phase sequence e. m. f. is given by P_N where

$$P_N = -\,3\ I_{a2}^2\ \frac{R_a'}{2} \quad (192)$$

this quantity must therefore be subtracted from the value of P_0 in all the equations in which P_0 appears when unbalanced circuits are used in connection with equations (**177**) to (**190**) inclusive. These equations, however, give the conditions for maintaining a given mechanical load and a given power factor in the positive phase sequence component, but in practice what is re-

quired is the combined power factor of the whole system, or the conditions to give a certain combined factor while delivering a given mechanical load; this may be obtained as follows:

The negative phase sequence component is a perfectly definite impedance and is independent of the load, and therefore the zero frequency part of the product $E_{a2}\, I_{a2}$ may be set down as

$$\check{E}_{a2}\, \hat{I}_{a2} = \frac{P_2}{3} + j\, \frac{Q_2}{3} \tag{193}$$

we have also for the positive phase sequence power delivered

$$(A_1 + j\, B_1)\, I_{a1} = I_{a1}^2\, R_a^1 + \frac{P_0}{3} - \frac{P_N}{3} + j\,(w\, I_{a1}\, L_a^1 + B_1^1)\, I_{a1} \tag{194}$$

And the power factor is given by

$$\tan \alpha = \frac{I_{a1}\, B_1 + \dfrac{Q_2}{3}}{I_{a1}\, A_1 + \dfrac{P_2}{3}} \tag{195}$$

From (**194**) we have

$$A_1\, I_{a1} = I_{a1}^2\, R_a^1 + \frac{P_0}{3} - \frac{P_N}{3} \tag{196}$$

$$B_1 = w\, I_{a1}\, L_a^1 + B_1^1 \tag{197}$$

$$A_1^2 + B_1^2 = E_{a1}^2 \tag{198}$$

The simplest method of solving these equations is by means of curves. Taking arbitrary values of I_{a1}, B_1 and A_1 are chosen consistent with (**198**) so as to satisfy (**195**), $\dfrac{P_0}{3}$ A_1' and B_1' are then obtained from (**196**) and (**197**). If there are harmonics in the impressed e. m. f. but there are none in the wave form of the machine, the machine will have a definite impedance to the positive and negative phase sequence components of each harmonic, so that there will be a definite amount of mechanical work contributed by each harmonic which must be subtracted from the total work to be done to give the amount of work contributed by the positive phase sequence fundamental component, the equations will be identical to (**193**), (**194**), (**195**), (**196**),

(**197**) and (**198**), if we take P_N to mean the total mechanical work done by the harmonics both positive and negative phase sequence and P_2 and Q_2 to represent the products

$$\Sigma \left({}_n\check{E}_{a1} \quad {}_n\hat{I}_{a1} + {}_n\check{E}_{a2} \quad {}_n\hat{I}_{a2} \right)$$

the zero frequency part only being taken into account.

When harmonics are present both in the impressed wave and in the generated wave, the problem becomes too complicated to treat generally, but specific cases can be worked out without much difficulty.

Phase Converters and Balancers

The phase converter is a machine to transform energy from single-phase or pulsating form to polyphase or non-pulsating form or vice versa to transform energy from polyphase to single-phase. The transformation may not be complete, that is to say, the polyphase system may not be perfectly balanced when supplied from a single-phase source through the medium of a phase converter. Phase converters may be roughly divided into two classes, namely—shunt type and series type.

Induction Motor or Synchronous Condenser Operating as a Phase Converter of the Shunt Type to Supply a Symmetrical Induction Motor or Synchronous Motor

Let Z_1 and Z_2 be the positive and negative phase sequence impedances of the motor, Z_1', Z_2' those of the phase converter. Let $S^1\, \check{E}_{a1}$ and $S^2\, \check{E}_{a2}$ be the positive and negative phase sequence components of the star e. m. f. impressed on the motor as a result of the operation. The single-phase supply will be one side of the delta e. m. f. $S\, \check{E}_{bc}$ which has positive and negative phase sequence components $S^1\, E_{bc1}$ and $S^2\, E_{bc2}$ the single-phase supply being $\check{E}_{bc} = \check{E}_{bc1} + \check{E}_{bc2}$.

The value of Z_2' may be considered fixed for all practical purposes and since in the induction motor phase converter the speed is practically no-load speed, Z' is practically the no-load impedance plus a real part obtained by increasing the real part of the no-load impedance by the ratio of the normal no-load losses to these same losses plus $\frac{1}{2}$ the secondary losses due to the phase converter currents. The latter may be calculated roughly as even a large error in its value will have an inappreciable effect on the actual results. We have therefore

$$\left.\begin{aligned} S^1\,\check{E}_{a1} &= -\,S^1\,j\,\frac{\check{E}_{bc}}{\sqrt{3}} \\ S^2\,\check{E}_{a2} &= \quad S^2\,j\,\frac{\check{E}_{bc2}}{\sqrt{3}} \end{aligned}\right\} \quad (\mathbf{199})$$

$$\left.\begin{aligned} S_1^1\,\check{I}_{a1}' &= -\,S^1\,j\,\frac{\check{E}_{bc1}}{\sqrt{3}\,Z_1'} \\ S^1\,\check{I}_{a1} &= -\,S^1\,j\,\frac{\check{E}_{bc1}}{\sqrt{3}\,Z_1} \end{aligned}\right\} \quad (\mathbf{200})$$

$$\left.\begin{aligned} S^2\,\check{I}_{a2}' &= \quad S^2\,j\,\frac{\check{E}_{bc2}}{\sqrt{3}\,Z_2'} \\ S^2\,\check{I}_{a2} &= \quad S^2\,j\,\frac{\check{E}_{bc2}}{\sqrt{3}\,Z_2} \end{aligned}\right\} \quad (\mathbf{201})$$

In the common lead of motor and converter we have

$$\check{I}_{a1}' + \check{I}_{a2}' + \check{I}_{a1} + \check{I}_{a2} = O \quad (\mathbf{202})$$

or, substituting from (**200**) and (**201**)

$$\check{E}_{bc2}\left(\frac{1}{Z_2'} + \frac{1}{Z_2}\right) = \check{E}_{bc1}\left(\frac{1}{Z_1'} + \frac{1}{Z_1}\right) \quad (\mathbf{203})$$

$$\frac{\check{E}_{bc1}}{\check{E}_{bc2}} = \frac{\dfrac{1}{Z_2'} + \dfrac{1}{Z_2}}{\dfrac{1}{Z_1'} + \dfrac{1}{Z_1}} \quad (\mathbf{204})$$

$$\check{E}_{bc1} = \frac{\dfrac{1}{Z_2} + \dfrac{1}{Z_2'}}{\left(\dfrac{1}{Z_1} + \dfrac{1}{Z_1'}\right) + \left(\dfrac{1}{Z_2} + \dfrac{1}{Z_2'}\right)}\,\check{E}_{bc} \quad (\mathbf{205})$$

$$\check{E}_{bc2} = \frac{\dfrac{1}{Z_1} + \dfrac{1}{Z_1'}}{\left(\dfrac{1}{Z_1} + \dfrac{1}{Z_1'}\right) + \left(\dfrac{1}{Z_2} + \dfrac{1}{Z_2'}\right)}\,\check{E}_{bc} \quad (\mathbf{206}).$$

which give the complete solution for all the quantities required with the aid of equations (**200**) and (**201**). For the supply current $\check{I}$

$$\left.\begin{aligned} \check{I} &= \check{I}_{bc1} + \check{I}_{bc2} + I_{bc1}' + I_{bc2}' \\ S\,\check{I}_{bc} &= S^1\,\check{I}_{bc1} + S^2\,\check{I}_{bc2} \\ S\,\check{E}_{bc} &= S^1\,\check{E}_{bc1} + S^2\,E_{bc2} \end{aligned}\right\} \quad (207)$$

$$P_1 + j\,Q_1 = \check{E}_{bc}\,\hat{I} \quad (208)$$

In order to obtain a perfect balance we may consider the addition of an e. m. f. $S^2\,j\,\dfrac{E_{x2}}{\sqrt{3}}$ in series with the phase converter whose value must be a function of the load and the phase converter impedances, and therefore equation (**201**) will be replaced by

$$S^2\,\check{I}_{a2}' = S^2\left(j\,\frac{\check{E}_{bc2}}{\sqrt{3}\,Z_2'} + j\,\frac{\check{E}_{x2}}{\sqrt{3}\,Z_2'}\right) \quad (209)$$

$$S^2\,\check{I}_{a2} = S^2\,j\,\frac{\check{E}_{bc}}{\sqrt{3}\,Z_2}$$

and since the balance is perfect $\check{E}_{bc2}$ is zero, and therefore

$$S^2\,j\,\frac{\check{E}_{x2}}{\sqrt{3}} = S^2\,Z_2'\,\check{I}_{a2}' \quad (210)$$

An e. m. f. equal and of opposite phase to the negative phase sequence drop through the phase converter is required to produce a perfect balance.

Carrying out the solution in the same manner as in the imperfect converter, we obtain

$$\check{E}_{bc2} = \frac{\dfrac{1}{Z_1} + \dfrac{1}{Z_1'}}{\dfrac{1}{Z_2} + \dfrac{1}{Z_2'}}\,E_{bc} - \frac{\dfrac{1}{Z_2'}}{\dfrac{1}{Z_2} + \dfrac{1}{Z_2'}}\,\check{E}_{x2} \quad (211)$$

and since $\check{E}_{bc2}$ is zero and $\check{E}_{bc1} = \check{E}_{bc}$ the single-phase impressed e. m. f., we obtain

$$\check{E}_{x2} = Z_2'\left(\frac{1}{Z_1} + \frac{1}{Z_1^1}\right)\check{E}_{bc} \quad (212)$$

and therefore from (**210**)

$$S^2\,\check{I}_{a2}' = S^2\,j\left(\frac{1}{Z_1} + \frac{1}{Z_1'}\right)\frac{\check{E}_{bc}}{\sqrt{3}} \quad (213)$$

$$S^1 \check{I}_{a1}{}^1 = - S^1 j \frac{\check{E}_{bc}}{\sqrt{3} Z_1{}'} \tag{214}$$

$$S^2 \check{I}_{a2} = O \tag{215}$$

$$S^1 \check{I}_{a1} = - S^1 j \frac{\check{E}_{bc}}{\sqrt{3}\ Z_1} \tag{216}$$

Figs. 9, 10, 11 and 12 are vector diagrams of some of the principal compensated shunt type phase converters. There will be no

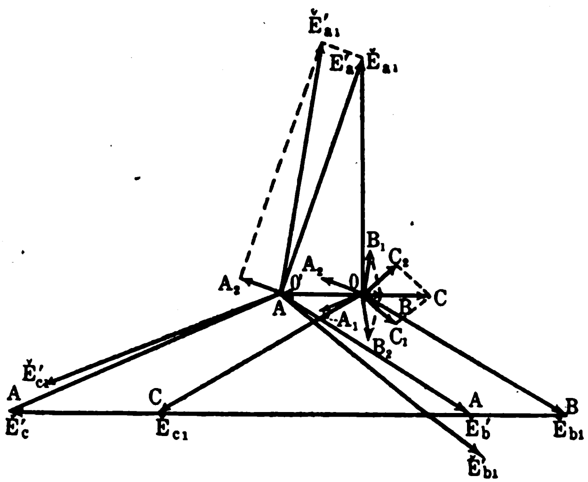

FIG. 9—VECTOR DIAGRAM OF SHUNT-TYPE PHASE CONVERTER OPERATED FROM TRANSFORMER SO AS TO DELIVER BALANCED CURRENTS

Terminal voltages of phase converter $S\check{E}^1{}_a$

Terminal voltages of motor $S^1\check{E}_{a1}$

Nega ive phase sequence e.m.fs. in phase converter $S^2\ (OA_2)$

difficulty in following out these diagrams if the principles of this paper have been grasped.

The Phase Balancer is a device to maintain symmetry of e. m. fs. at a given point in a polyphase system. It may consist of an induction motor or synchronous condenser with an auxiliary machine connected in series to supply an e. m. f. always proportional to the product of the negative phase sequence current passing through the machine and the negative phase sequence impedance of the balancer. It therefore has the effect of annulling the impedance of the machine to the flow of negative phase sequence current. Thus, in a symmetrical polyphase

network, where we have an unbalanced system of currents due to certain conditions

$$S\,\check{I}_a = S^1\,\check{I}_{a1} + S^2\,\check{I}_{a2} \tag{217}$$

If a balancer be placed at the proper point the component $S^2\,\check{I}_{a2}$ will circulate between the loads and the phase balancer, the other component $S^1\,I_{a1}$ being furnished from the power house. On the other hand, if there be a dissymmetry in the impedance of the system up to the phase balancer, the latter will draw a negative phase sequence current sufficient to counteract the unbalance

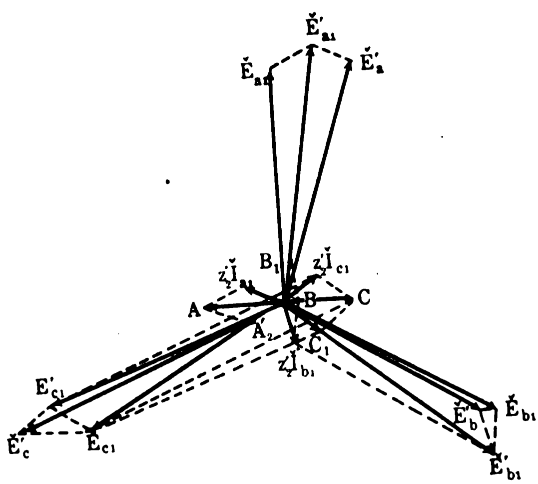

FIG. 10—VECTOR DIAGRAM SHOWING RELATIONS BETWEEN MOTOR TERMINAL E.M.F'S., CONVERTER TERMINAL E.M.FS., AND SYMMETRICAL GENERATED E.M.F'S., SAME CONNECTION AS FOR FIG. 9.

Negative phase sequence drops in phase converter $S^2 Z_2{}^1 \check{I}_{a1}$

Conjugate positive phase sequence e.m.fs. $S^1(ABC)$

due to any symmetrical load by causing the proper amount of negative phase sequence current to flow to produce a balance.

The balancer may be made inherently self-balancing by inserting in series with it a machine which is self-exciting and is able to furnish an e. m. f. equal to the negative phase sequence impedance drop. The combination thus has zero impedance to negative phase sequence currents. If in the neighborhood of a phase balancer the loads have impedances

$$S\,Z_a = S^0\,Z_{a0} + S^1\,Z_{a1} + S^2\,Z_{a2}$$

The equations of the system are

$$\left.\begin{aligned} S^1 \check{E}_{a1} &= S^1 Z_{a0} \check{I}_{a1} + S^1 Z_{a2} \check{I}_{a2} \\ S^2 E_{a2} &= O = S^2 Z_{a0} \check{I}_{a2} + S^2 Z_{a1} \check{I}_{a1} \end{aligned}\right\} \quad \textbf{(218)}$$

The currents in the phase converter are

$$- S^2 \check{I}_{a2} \text{ and } S^1 \frac{\check{E}_{a1}}{Z_1{}^1}$$

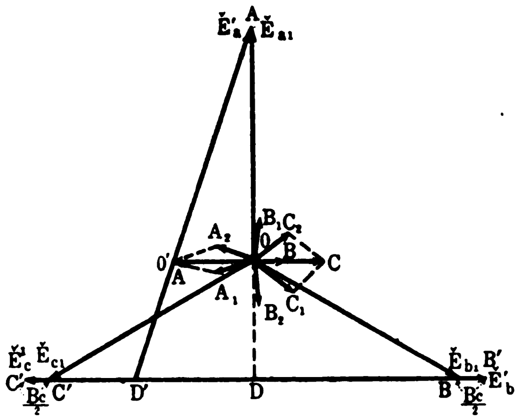

FIG. 11—VECTOR DIAGRAM OF SHUNT TYPE PHASE CONVERTER SCOTT CONNECTED WITH COMPENSATION BY TRANSFORMER TAPS
Terminal voltages of converter O^1A and B^1C^1
Terminal voltages of motor $S^1\check{E}_{a1}$

The solution of (**218**) gives $S^2 \check{I}_{a2}$ and $S^1 \check{I}_{a1}$, the former of which are the phase balancer currents. The solution is

$$\left.\begin{aligned} \check{I}_{a1} &= \frac{Z_{a0}}{Z_{a0}{}^2 - Z_{a1} Z_{a2}} \check{E}_{a1} \\ \check{I}_{a2} &= - \frac{Z_{a1}}{Z_{a0}{}^2 - Z_{a1} Z_{a2}} \check{E}_{a1} \end{aligned}\right\} \quad \textbf{(219)}$$

The phase balancer is a voltage balancer and will maintain balanced e. m. f. for any condition of impedance, and if the impedance of the mains is unsymmetrical it will draw a sufficient amount of wattless negative phase sequence current through these mains to produce an e. m. f. balance at its terminals. Hence the complete solution requires consideration of all the

connections in the network between the supply point and the balancer. Two equations for each mesh and connection are required, one of the positive phase sequence e. m. fs. and the other of the negative phase sequence e. m. f., and these equations may be solved in the usual way.

Series Phase Converter. In discussing the various reaction in rotating machines we have made use of the terms "positive phase sequence impedance" and "negative phase sequence impedance." These terms are definite enough when dealing with relations between machines whose generated e. m. fs. all have the

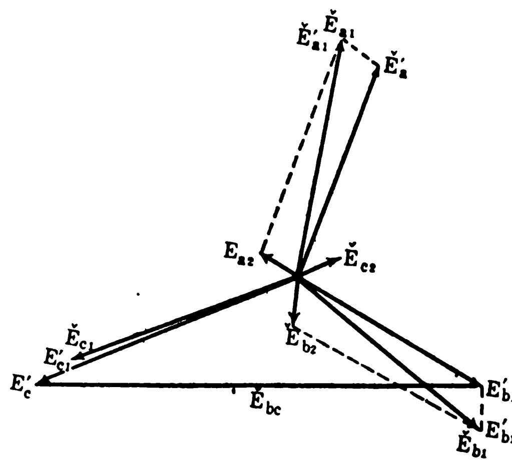

FIG. 12—VECTOR DIAGRAM OF SHUNT-TYPE PHASE CONVERTER WITH AUXILIARY ROTATING COMPENSATOR TO EFFECT A PERFECT BALANCE

Terminal voltages of phase converter $S\,\check{E}_a{}^1$
Terminal voltages of motor $S^1\check{E}_{a1}$
Terminal voltages of compensator $S^2\check{E}_{a2}$

same phase sequence, but require further definition when we are dealing with relations between machines whose e. m. fs. have different phase sequence. We shall retain the symbols Z_1 and Z_2 for the values of the positive and negative phase sequence impedances, depending upon the sequence symbol S to define whether these impedances apply to a negative or positive phase sequence current. Thus, the phase sequence of the currents and e. m. f. will be defined by the apparatus supplying and receiving power and the impedances of the transmitting apparatus will be defined in relation to these currents. As an example a motor

series connected in counter phase sequence relation in a circuit and driven in a positive direction will have impedances

$$\left.\begin{array}{l}\text{positive phase sequence } Z_2\\[2ex]\text{negative phase sequence } Z_1\end{array}\right. \qquad (220)$$

Where an auxiliary machine is defined as being of negative phase sequence relation to other machines, it will have impedances as given above to the positive and negative phase sequence currents passing through the other machines.

A single-phase transformer winding tapped at the middle point

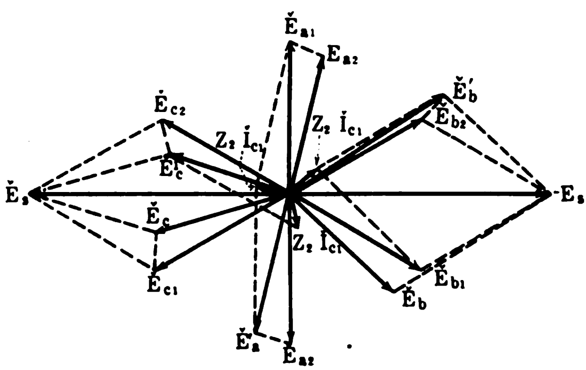

FIG. 13—VECTOR DIAGRAM OF SERIES-TYPE CONVERTER.
NO LOAD E.M.F'S. ACROSS MOTOR TERMINALS $S_1\check{E}_{a1}$
NO LOAD E.M.F'S. ACROSS CONVERTER TERMINALS $S^2\check{E}_{a2}$
SINGLE-PHASE E.M.F'S. $2\check{E}_s$
E.M.F. ACROSS TERMINAL OF MOTOR UNDER LOAD $\check{E}_a\check{E}_a\check{E}_c$
E.M.F. ACROSS TERMINAL OF CONVERTER UNDER LOAD $\check{E}_a\check{E}_b\check{E}_c$

may be regarded as an unbalanced three-phase system where

$$\check{E}_a = O \quad \check{E}_b = + \check{E}_s \quad \check{E}_c = - \check{E}_s$$

$2\,\check{E}_s$ being the single-phase e. m. f The system may be represented by the equation

$$\left.\begin{aligned} S\,\check{E}_a &= S^1\,\check{E}_{a1} + S^2\,\check{E}_{a2} \\ \text{where } \check{E}_{a1} &= \quad j\,\frac{\check{E}_s}{\sqrt{3}} \\ \check{E}_{a2} &= -\,j\,\frac{\check{E}_s}{\sqrt{3}} \end{aligned}\right\} \qquad (221)$$

If, therefore between the single-phase source of power and the load we interpose a polyphase machine with e. m. f. $- S^2 \check{E}_{a2}$, we shall have at the load terminals the e. m. f. $S^1 \check{E}_{a1}$. If we use an induction type phase converter it will have impedances to motor currents as follows

$$\left.\begin{array}{l} \text{To positive phase sequence } Z_2' \\ \text{To negative phase sequence } Z_1' \end{array}\right\} \quad (222)$$

we therefore have the relations

$$S^1 \check{E}_{a1} = S^1 \check{I}_{a1} (Z_1 + Z_2') \quad (223)$$

$$S^2 \check{E}_{a2} = S^2 \check{I}_{a2} (Z_2 + Z_1') \quad (224)$$

If the converter is doing no mechanical work, Z_1' is large compared with Z_2' or Z_2, and therefore the component of negative phase sequence is small in the motor. The value of Z_1' depends upon the slip of the phase converter which will depend on the mechanical load it carries as well as on the load carried by the motors. Approximately the load currents due to the motors produce the equivalent at the phase converter of a mechanical load equal to one-half the rotor loss of the phase converter due to these load currents. Substituting the values given in (**221**) for $S^1 \check{E}_{a1}$ and $S^2 \check{E}_{a2}$, we obtain

$$\left.\begin{array}{rl} S^1 j \dfrac{\check{E}_s}{\sqrt{3}} &= S^1 \check{I}_{a1} (Z_1 + Z_2') \\ - S^2 j \dfrac{E_s}{\sqrt{3}} &= S^2 \check{I}_{a2} (Z_2 + Z_1') \end{array}\right\} \quad (225)$$

$$\left.\begin{array}{rl} S^1 \check{I}_{a1} &= S^1 j \dfrac{\check{E}_s}{\sqrt{3}\,(Z_1 + Z_2')} \\ S^2 \check{I}_{a2} &= - S^2 j \dfrac{\check{E}_s}{\sqrt{3}\,(Z_2 + Z_1')} \end{array}\right\} \quad (226)$$

If instead of an induction type phase converter a synchronous phase converter is used an e. m. f. of negative phase sequence $S^2 \check{E}_{a2}$ *the generated e. m. f. of the phase converter must be introduced in equations* (**224**) *and* (**225**) *and the value and phase of these e. m. fs. will depend upon the load on the phase converter shaft as well as the load carried by the motors.* The equations will be

$$S^1 \check{E}_{a1} = S^1 \check{I}_{a1} (Z_1 + Z_2') \tag{227}$$

$$S^2 \check{E}_{a2} = S^2 \check{I}_{a2} (Z_2 + Z_1') + S^2 \check{E}_{a2}' \tag{228}$$

or

$$\left.\begin{aligned} S^1 j \frac{\check{E}_s}{\sqrt{3}} &= S^1 \check{I}_{a1} (Z_1 + Z_2') \\ - S^2 j \frac{\check{E}_s}{\sqrt{3}} &= S^2 \check{I}_{a2} (Z_2 + Z_1') + S^2 \check{E}_{a2}' \end{aligned}\right\} \tag{229}$$

The last member of equations (**229**) is the equation of a synchronous condenser. Assuming its windage, iron loss and increased losses due to secondary reactions to be P_0, we have by equation (**160**) of the Section on Synchronous Motors

$$\frac{E_s}{\sqrt{3}} I_{a2} \cos \alpha = I_{a2}^2 (R_2 + R_1') + \frac{P_0}{3} \tag{230}$$

Let

$$\check{I}_{a2} = a_2 + j\, b_2 \tag{231}$$

then (**230**) becomes

$$\frac{E_s}{\sqrt{3}} a_2 = (a_2^2 + b_2^2)(R_2 + R_1') + \frac{P_0}{3} \tag{232}$$

Of the two quantities a_2 and b_2, b_2 alone is arbitrary and depends upon the excitation, a_2 will depend upon the value of b_2 and also upon the losses. Solving therefore for a_2 in terms of b_2, we have

$$a_2 = \frac{E_s}{2\sqrt{3}(R_2 + R_1')} \left\{ 1 - \sqrt{1 - \frac{4 (R_2 + R_1') \{3 b_2^2 (R_2 + R_1') + P_0\}}{E_s^2}} \right\} \tag{233}$$

Since b_2 is arbitrary we may now determine $\cos \alpha_2 = \frac{a_2}{\sqrt{a_2^2 + b_2^2}}$ and the value of $\check{I}_{a2}$ in terms of the impressed e. m. f. will be by (**181**) of Section on Synchronous Motors

$$S^2 \check{I}_{a2} = - S^2 \left[j \frac{\check{E}_s}{\sqrt{3}} \frac{\cos \alpha_2}{2 (R_2 + R_1')} \left\{ 1 - \sqrt{1 - \frac{4 (R_2 + R_1') P_0}{E_s^2 \cos^2 \alpha_2}} \right\} \epsilon^{j\alpha} \right] \tag{234}$$

The effective value of $\check{I}_{a2}$ in terms of the effective value of $\check{E}_s$ will then be

$$I_{a2} = \frac{E_s}{\sqrt{3}} \frac{\cos \alpha_2}{2\,(R_2 + R_1')} \left\{ 1 - \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}} \right\} \tag{235}$$

and since the component of the e.m.f. generated in phase with the current is determined only by the magnitude of $\check{I}_{a2}$ and the motor losses, if we define its value by A_2' the quadrature component being B_2' we shall have

$$A_2' = \frac{E_s}{\sqrt{3}} \frac{\cos \alpha_2}{2} \left(1 + \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}} \right) \tag{236}$$

and

$$B_2' = - \frac{E_s}{\sqrt{3}} \sin \alpha_2 - \frac{w\,(L_2 + L_2')}{A_2^1} \tag{237}$$

$$= - \frac{E_s}{\sqrt{3}} \left\{ \sin \alpha_2 + \frac{3\,w\,(L_2 + L_1')}{P_0} \cdot \frac{\cos \alpha_2}{2\,(R_2 + R_1')} \left(1 - \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}} \right) \right\} \tag{238}$$

and therefore we have

$$\check{E}_2' = -j \frac{E_s}{\sqrt{3}} \left[\frac{\cos \alpha_2}{2} \left(1 + \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}} \right) - j \left\{ \sin \alpha_2 + \frac{3\,w\,(L_2 + L_1') \cos \alpha_2}{2\,P_0\,(R_2 + R_1')} \left(1 - \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}} \right) \right\} \right] \tag{239}$$

The impedance of the phase converter to the flow of negative phase sequence current is

$$\frac{2\,(R_2 + R_1') \sec \alpha}{1 - \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha}}} \tag{240}$$

The balance will be at its best when $\check{I}_{a2}$ is a minimum with $\cos \alpha_2$ as the independent variable. This will be the case when $\cos \alpha_2$ is unity; that is to say when b_2 is zero.

Recapitulating the results given above, we have for the general case taking the single-phase e. m. f. $\check{E}_s$ as reference

$$S^1 \check{I}_{a1} = S^1 j \frac{\check{E}_s}{\sqrt{3}\,(Z_1 + Z_2')} \tag{241}$$

$$S^2 \check{I}_{a2} = -j\,(a_2 + j\,b_2) \tag{242}$$

where b_2 is arbitrary and

$$a_2 = \frac{E_s}{2\sqrt{3}\,(R_2 + R_1')} \left\{ 1 - \sqrt{1 - \frac{4\,(R_2 + R_1')\,\{3\,b_2^2\,(R_2 + R_1') + P_0\}}{E_s^2}} \right. \tag{243}$$

Since b_2 is arbitrary $\cos \alpha_2$ is determined by

$$\cos \alpha_2 = \frac{a_2}{\sqrt{a_2^2 + b_2^2}} \tag{244}$$

we may express $\check{I}_{a2}$ in terms of $\check{E}_s$ by

$$S^2 I_{a2} = -S^2 j \frac{\check{E}_s}{\sqrt{3}} \frac{\cos \alpha_2}{2\,(R_2 + R_1')} \left\{ 1 - \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}} \right\} \epsilon^{j\alpha_2} \tag{245}$$

The effective value of $\check{I}_{a2}$ will be

$$I_{a2} = \sqrt{a_2^2 + b_2^2} = \frac{E_s}{\sqrt{3}} \frac{\cos \alpha_2}{2\,(R_2 + Q_1')} \left\{ 1 - \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}} \right\} \tag{246}$$

If A_2' and B_2' are components of $\check{E}_{a2}'$ these being the generated e. m. f. in phase and in quadrature with the current $\check{I}_{a2}$ we shall have

$$\check{E}_{a2}' = -j\,(A_2' + j\,B_2') \tag{247}$$

and A_2' and B_2' will have the following values

$$A_2' = \frac{E_s}{\sqrt{3}} \; \frac{\cos \alpha_2}{2} \left(1 + \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}}\right) \tag{248}$$

$$B_2^1 = - \frac{E_s}{\sqrt{3}} \left\{ \sin \alpha_2 + \frac{3\,w\,(L_2 + L_1')}{P_0} \cdot \frac{\cos \alpha_2}{2\,(R_2 + R_1')} \left(1 - \sqrt{1 - \frac{4\,(R_2 + Q_1')\,P_0}{E_s^2 \cos \alpha^2}}\right)\right\} \tag{249}$$

and $\check{E}_{a2}'$ expressed in terms of $\check{E}_s$ becomes

$$\check{E}_2' = - j \frac{\check{E}_s}{\sqrt{3}} \left[\frac{\cos \alpha_2}{2} \left(1 + \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}}\right) - j \left\{ \sin \alpha_2 + \frac{3\,w\,(L_2 + L')\cos \alpha_2}{2\,P_0\,(R_2 + R_1')} \left(1 - \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}}\right)\right\}\right] \tag{250}$$

The effective impedance of the phase converter to the flow of negative phase sequence currents is

$$\frac{2\,(R_2 + R_1') \sec \alpha_2}{1 - \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha}}} (\cos \alpha_2 - j \sin \alpha_2) \tag{251}$$

or

$$\frac{E_s^2}{P_0} \cdot \frac{\cos \alpha_2}{2} \left(1 + \sqrt{1 - \frac{4\,(R_2 + R_1')\,P_0}{E_s^2 \cos^2 \alpha_2}}\right) e^{-j\alpha_2} \tag{252}$$

In the above equations $\cos \alpha_2$ is arbitrary or b_2 may be considered arbitrary and $\cos \alpha_2$ will then be determined.

Minimum Unbalance is obtained when $\cos \alpha_2$ is made unity or when b_2 is made zero in equations (**241**) and (**252**).

Perfect Balance is obtained by driving the phase converter mechanically so as to supply the mechanical power P_0 from a separate or symmetrical source. Under this condition a_2 and b_2 both become zero when $\cos \alpha_2$ is unity. The only equation of the system is then (**241**).

Currents and Power Factor in the Single-Phase Supply Circuit. The e. m. f. is $2\,\dot{E}_s$ and the current supplied is

$$\dot{I}_s = \frac{\dot{I}_b - \dot{I}_c}{2}$$

$$= \frac{\dot{I}_{b1} - \dot{I}_{c1}}{2} + \frac{\dot{I}_{b2} - \dot{I}_{c2}}{2} \tag{253}$$

If we take

$$S^1\,\dot{I}_{a1} = S^1\,j\,(a_1 - j\,b_1) \tag{254}$$

$$\frac{\dot{I}_{b1} - \dot{I}_{c1}}{2} = \frac{\sqrt{3}}{2}\,(a_1' - j\,b_1) \tag{255}$$

Similarly, since under the same conditions

$$S^2\,\dot{I}_{a2} = -\,S^2\,j\,(a_2 + j\,b_2) \tag{256}$$

$$\frac{\dot{I}_{b2} - \dot{I}_{c2}}{2} = \frac{\sqrt{3}}{2}\,(a_2 + j\,b_2) \tag{257}$$

and therefore

$$\dot{I}_s = \frac{\sqrt{3}}{2}\,\{(a_1 + a_2) - j\,(b_1 - b_2)\} \tag{258}$$

where a_1, b_1, a_2, b_2 are to be obtained by means of equations (**243**) to (**254**). The single-phase power factor is given by

$$\tan\,\theta = \frac{b_1 - b_2}{a_1 + a_2} \tag{259}$$

of these quantities a_2 is usually the smallest and its value may be obtained approximately by assigning to b_2 a value which will make the ratio $\dfrac{b_1 - b_2}{a_1}$ equal to tan θ, and obtaining the corresponding value of a_2 by (**242**), the value of b_2 may then be recalculated from (**259**) by substituting the tentative value obtained for a_2. This procedure may be repeated until sufficient accuracy has been obtained.

Single Phase Power Factor in Shunt Type Phase Converter

The simplest procedure is to obtain a curve of admittances for varying excitation of the converter and plot the power factor obtained by varying the admittance with a fixed load. The true

and wattless power is obtained easily by means of (208) whether the system is balanced or unbalanced.

Figs. 14, 15, 16 and 17 are vector diagrams of several methods of using phase converters to supply a balanced 3-phase e. m. f. to a symmetrical load such as an induction motor. The diagram are all based on a main machine having the same negative phase sequence impedance and the system in each case is

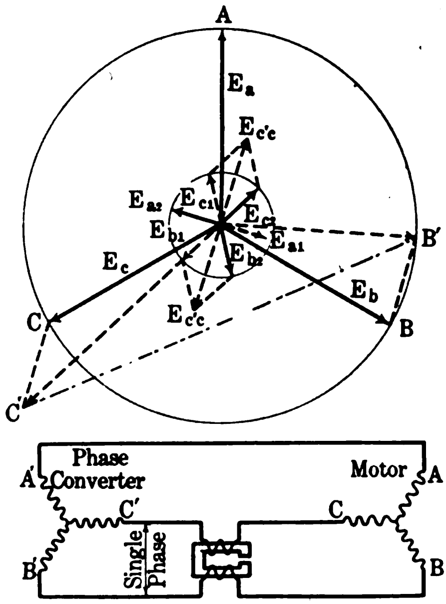

Fig. 14
Single -Phase Impressed e.m.f. = $B'C'$
Motor e.m.f. = BC
Negative Phase Sequence e.m.fs. $\check{E}_{a2}\check{E}_{b2}\check{E}_{c2}$
Conjugate Positive Phase Sequence e.m.fs. $\check{E}_{a1}\check{E}_{b1}\check{E}_{c1}$
Phase Converter Terminal e.m.f. $AB'C'$

delivering the same amount of power at the same voltage and 3-phase power factor without supplying any wattless power. It will be noted that the scheme Fig. 14 has the lowest single phase power factor, Fig. 16 the highest and the rest arcing alike. It may be remarked, however, that with the shunt type schemes adjustments can be made for power factor correction which will result also in better regulation.

APPENDIX I

Cylindrical Fields in Fourier Harmonics

When we have a diametrical coil around a cylinder concentric with another cylinder which forms the return magnetic path, and the length of the gap is uniform and the coil dimension very small, the field across the gap takes the form of a square topped

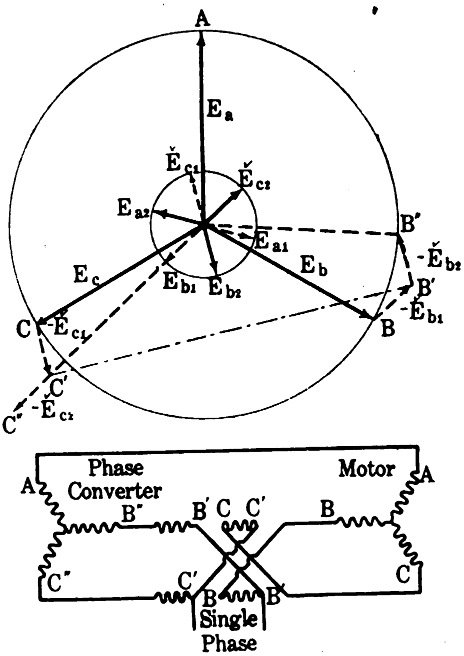

FIG. 15

SINGLE PHASE IMPRESSED E.M.F. = $B'C'$
MOTOR E.M.F. = BC
PHASE CONVERTER E.M.F. = $B''C''$
NEGATIVE PHASE SEQUENCE E.M.F $\breve{E}_{a2}\breve{E}_{b2}\breve{E}_{c2}$
CONJUGATE POSITIVE PHASE SEQUENCE E.M.F. $\breve{E}_{a}{}^{1}E_{b1}E_{c1}$
PHASE CONVERTER TERMINAL E.M.F. $AB''C''$

wave, which may be expressed in the form of a Fourier series with the plane of symmetry of the coil as reference plane, and its Fourier expansion is

$$\mathfrak{B} = \frac{4\,B}{\pi}\left(\cos\theta - \tfrac{1}{3}\cos 3\,\theta + \frac{1}{S}\cos S\,\theta - \,.\,.+\,.\,.\right) \qquad (1)$$

where B is the average induction in the air gap.

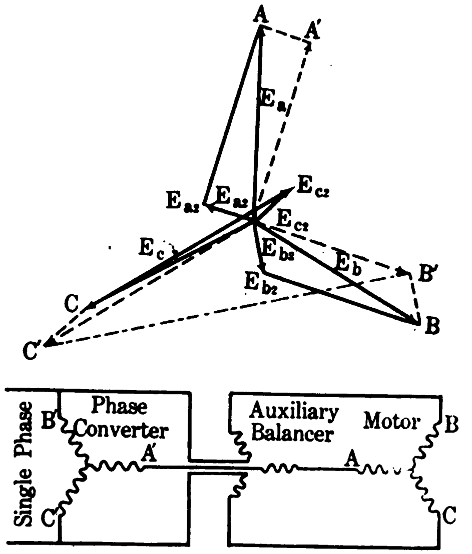

FIG. 16—PHASE CONVERTER WITH AUXILIARY BALANCER.

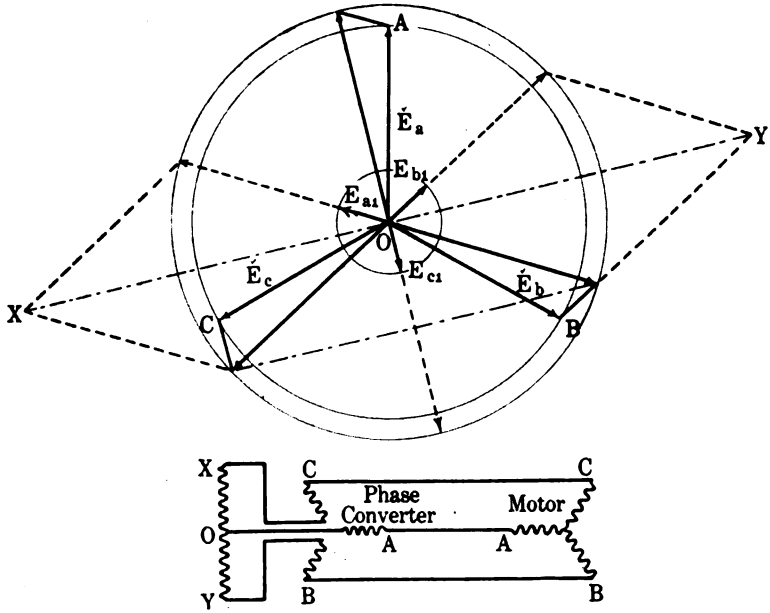

FIG. 17

SINGLE PHASE IMPRESSED E.M.F. = XY

MOTOR E.M.F. = BC

THERE IS A 2 TO 1 TRANSFORMATION OF E.M.F. FROM SINGLE-PHASE TO THREE-PHASE IN THIS CONNECTION

With pitch less than π the curve will have a different form, the amplitude being greater on one side of the plane of the coils than on the other, the areas of each wave will remain the same and second harmonic terms will appear. Let $2\,m_0\,\pi$ be the new pitch then the average amplitude of the induction will be the same as before, namely B, and the value on one side of the coil will be $2\,(1 - m_0)B$ and on the other side $2\,m_0\,B$ so that the total flux will be the same on either side. To obtain the values of the coefficients we have

$$2\,(1 - m_0 B \int_0^{m_0\pi} \cos n\,\theta\,d\,\theta + 2\,m_0\,B \int_{m_0\pi}^{2\pi} \cos n\,\theta\,d\,\theta = \frac{\pi}{2} A_n$$

$$2\,(1 - m_0)\,B \left[\frac{1}{n} \sin n\,\theta\right]_0^{m_0\pi} - 2\,m_0\,B \left[\frac{1}{n} \sin n\,\theta\right]_{m_0\pi}^{2\pi} = \frac{\pi}{2} A_n$$

$$A_n = \frac{4\,B}{\pi} \left\{ \frac{(1\ \ m_0) + m_0}{n} \sin n\,m_0\,\pi \right\}$$

$$A_n = \frac{4\,B}{\pi} \left(\frac{1}{n} \sin n\,m_0\,\pi_1\right) \tag{2}$$

Let $2\,m_0\,\pi = \frac{2}{3}\,\pi$, then $(1 - m_0)\,\pi = \frac{2}{3}\,\pi$ and

$$\mathfrak{B} \doteq \frac{2\sqrt{3}\,B}{\pi} \left(\cos\theta + \frac{1}{2}\cos 2\,\theta - \frac{1}{4}\cos 4\,\theta - \frac{1}{5}\cos 5\,\theta\right.$$
$$\left. + \frac{1}{7}\cos 7\,\theta + \frac{1}{8}\cos 8\,\theta - \frac{1}{10}\cos 10\,\theta\ .\ .\ .\right) \tag{3}$$

A general expression for $\mathfrak{B}$ where B is the average of the positive and negative, maximum value for any pitch coil would be

$$\mathfrak{B} = \frac{4\,B}{\pi}\,\Sigma \left(\frac{1}{n} \sin n\,m_0\,\pi \cos n\,\theta\right) \tag{4}$$

and includes all possible coil pitches. If the number of teeth in a pole pitch be n_T; in addition to the average induction as indicated by (4), there will also be a tooth ripple of flux, the maximum value of which will depend upon the average value of the induction at each point. The value of m_0 must be a fraction having n_T as denominator and an integral numerator. The

value of the integral numerator is therefore always $m_0\, n_T$. The correct value for the max. induction will therefore be

$$\mathfrak{B}_m = \left\{ \frac{4\,B}{\pi}\, \Sigma \left(\frac{1}{n} \sin n\, m_0\, \pi \cos n\, \theta \right) \right\} (1 - (-1)^{m_0 n_T} K_T \cos n_T\, \theta) \qquad (5)$$

where K_T is the ratio of the average to the min. air gap. "m_0" must always be chosen so that $m_0\, n_T$ is an integer.

If the length of the average effective air gap in centimeters be d the value of B is given by

$$B = \frac{4\,\pi}{10}\ \frac{I\,N}{2\,d} \text{ gauss}$$

where I is the maximum value of the current in the coil and N is the number of turns. If d is given in inches we may write

$$B = \frac{4\,\pi}{10}\ \frac{I\,N}{2\,d} \times 2.54 \quad \text{maxwells per square inch.}$$

If we integrate (5) between the limits $(\theta - m_0\, \pi)$ and $(\theta + m_0\, \pi)$ we shall have the total flux φ through the coil

$$\varphi = \frac{4\,B\,r\,l}{\pi} \int_{\theta - m_0 \pi}^{\theta + m_0 \pi} \Sigma \left(\frac{1}{n} \sin n\, m_0\, \pi \cos n\, \theta \right) d\,\theta$$

$$- \frac{4\,B\,r\,l}{\pi} (-1)^{m_0 n_T} \int_{\theta - m_0 u}^{\theta + m_0 \pi} \Sigma \left(\frac{1}{n} \sin n\, m_0 (\cos n\, \theta \right) K_T \cos n_T\, \theta\, d\, 0$$

$$= \frac{4\,B\,re}{\pi} \left[\frac{1}{n^2} \sin n\, m_0\, \pi \sin n\, \theta \right]_{\theta - m_0 \pi}^{\theta + m_0 \pi}$$

$$- \frac{4\,B\,r\,l}{\pi} (-1)^{m_0 n_T} K_T\, \Sigma \frac{1}{n}\, \theta\, n\, m_0\, n\, \pi \left[\frac{\sin (n - n_T)\, \theta}{2\,(n - n_T)} + \frac{\sin (n + n_T\, \theta)}{2\,(n + n_T)} \right]_{\theta - m_0 \pi}^{\theta + m_0 \pi} \qquad (6)$$

The second expression is zero for all values of θ which are integral multiples of the tooth pitch angle, so long as $m_0\, n$ is also an integer and therefore it is zero for all mutual inductive relations of similar coils on a symmetrical toothed core we therefore have:

The induction through a coil displaced an angle θ from the axis of a similar coil carrying a current giving a mean induction B both coils being wound on the same symmetrical toothed core is

$$\varphi = \frac{8\,B\,r\,l}{\pi}\;\Sigma\left(\frac{1}{n^2}\sin^2 n\,m_0\,\pi\cos n\,\theta\right) \tag{7}$$

The second term in equation (6) also becomes zero when n_r becomes infinite independent of the value of θ. We may therefore safely make use of an imaginary uniformly distributed winding when considering self and mutual impedances. It will also be shown later on that with certain groupings of windings the second term may be reduced to zero for every value of θ.

If N_1 be the total number of complete loops in one complete pole pitch, we may take $\frac{N_1}{2\,\pi}$ as the density of winding per unit angle of the complete pole pitch. The mutual induction per turn in a coil angularly displaced an angle θ_1 from another coil of winding density $\frac{N_1}{2\,\pi}$ with an effective total air gap $2\,d$ and with windings subtending an angle $2\,m_1\,\pi$ is given by

$$M_1 = \frac{8\,N_1\,r\,l}{10^9\,\pi\,d}\int_{-m_1\pi}^{+m_1\pi}\Sigma\left\{\frac{1}{n^2}\sin^2 n\,m_0\,\pi\cos n(\theta+\theta_1)\right\}d\,\theta'\text{ henrys} \tag{8}$$

$$= \frac{8\,N_1\,r\,l}{10^9\,\pi\,d}\;\Sigma\;\frac{1}{n^3}\sin^2 n\,m_0\,\pi\left[\sin n\,(\theta+\theta_1)\right]_{\theta'=-m_1\pi}^{\theta'=m_1\pi}\text{ henrys}$$

$$M_1 = \frac{16\,N_1\,r\,l}{10^9\,\pi\,d}\Sigma\left(\frac{1}{n^3}\sin^2 n\,m_0\,\pi\sin n\,m_1\,\pi\cos n\,\theta\right)\text{henrys} \tag{9}$$

Next, if the loop of which M_1 is the mutual inductance is part of a winding having distribution density of winding $\frac{N_2}{2\,\pi}$ and subtending an angle $2\,m_2\,\pi$ its mutual inductance with the other winding will be

$$M_{12} = \frac{8\,N_1\,N_2\,r\,l}{10^9\,\pi^2\,d}\int_{-m_2\pi}^{m_2\pi}\Sigma\frac{1}{n^3}\sin^2 n\,m_0\,\pi\sin n\,m_1\,\pi\cos n\,(\theta+\theta^1)\,d\,\theta'\text{ henry} \tag{10}$$

$$= \frac{8\,N_1\,N_2\,r\,l}{10^9\,\pi^2\,d}\Sigma\;\frac{1}{n^4}\sin^2 n\,m_0\,\pi\sin n\,m_1\,\pi\left[\sin n\,(\theta+\theta_1)\right]_{\theta'=-m_2\pi}^{\theta'=m_2\pi}\text{ henrys}$$

$$M_{12} = \frac{16\, N_1\, N_2\, r\, l}{10^9\, \pi^2\, d}\, \Sigma \left(\frac{1}{n^4} \sin^2 n\, m_0\, \pi \sin n\, m_1\, \pi \sin n\, m_2\, \pi \cos n\, \theta \right) \text{henrys} \qquad (11)$$

This is the general expression for the mutual inductance between two groups of connected coils of like form on the same cylindrical core. It should be noted how much the harmonics have been reduced due to grouping.

When the coils are not of like design as in the case of a rotor and stator and the pitch of the coils is different in one from the other, $\sin n\, m_0\, \pi$ will not appear twice in the equation but one of its values must be replaced by $\sin n\, m_x\, \pi$ where $2\, m_x\, \pi$ is the pitch of the new coil. Equation (**11**) then becomes

$$M_{1a} = \frac{16\, N_1\, N_a\, r\, e}{10^9\, \pi^2\, d}\, \Sigma \left(\frac{1}{n^4} \sin n\, m_0\, \pi \sin n\, m_x\, \pi \sin n\, m_1\, \pi \sin n\, m_2\, \pi \cos n\, \theta \right) \text{henrys} \qquad (12)$$

This formula is strictly correct when m_x is an integer and when θ is an integral multiple of the tooth pitch. It is true for all values of θ if either m_0 or m_x or both are unity.

By considering the axes of two similar groups of coils as coincident we obtain the value of $\Delta_1\, L_1$ which is part of the self inductance of the group, thus

$$\Delta_1\, L_1 = \frac{16\, N_1^2\, r\, e}{10^9\, \pi^2\, d}\, \Sigma \left(\frac{1}{n^4} \sin^2 n\, m_0\, \pi \sin^2 n\, m_1\, \pi \right) \qquad (13)$$

The other factor that enters into the self inductance is the slot leakage inductance which depends upon the number of turns in a coil, the number of coils in a group and the width and depth of the slot and the length of the air gap. Since with the value of $\Delta_1\, L_1$ all the field which links the secondary winding has been included, only the portion of the slot leakage which does not link all the turns in the opposed secondary coil should be considered. No hard and fast rule can be made for determining this quantity since it depends upon the shape of the slots, there should be little trouble in making the calculation when the data is given. Denoting this quantity by $\Delta_2\, L_1$ we have

$$L_1 = \Delta_1\, L_1 + \Delta_2\, L_1 \qquad (14)$$

Symmetrically Grouped Windings. The above formulae give the mutual impedance between groups of coils, each group of which may be unsymmetrical. Generally machines are designed so that, although the individual groups of coils due to fractional pitch may be unsymmetrical, the complete winding is symmetrical. When two coils are together in a slot this may be done by connecting one group of coils opposite the north pole in series with the corresponding group opposite the south pole; that is to say, the group displaced electrically by the angle π. If therefore we take equation (**11**) and consider the mutual induction as due to a group having axis at θ = zero and another having its axis at $\theta = \pi$ with a similarly arranged group of coils having its axis at θ, we find that (**11**) becomes

$$M_{12} = \frac{16\, N_1\, N_2\, r\, l}{10^9\, \pi^2\, d}\, \Sigma \left\{ \frac{1}{n^4} \sin^2 n\, m_0\, \pi \sin n\, m_1\, \pi \right.$$
$$\left. \sin n\, m_2\, \pi\, (1 - \cos n\, \pi)^2 \cos n\, \theta \right\} \text{henrys} \qquad (15)$$

Similarly

$$M_{1a} = \frac{16\, N_1\, N_a\, r\, l}{10^9\, \pi^2\, d}\, \Sigma \left\{ \frac{1}{n^4} \sin n\, m_1\, \pi \sin n\, m_x \right.$$
$$\left. \pi \sin n\, m_1\, \pi \sin n\, m_a\, \pi\, (1 - \cos n\, \pi)^2 \cos n\, \theta \right\} \text{henrys} \qquad (16)$$

Since $1-\cos n\pi$ is zero for all even values of n it is evident that (**15**) and (**16**) contain no even harmonics, moreover the above formulae give the mutual induction between two similarly connected groups of windings, but if $(1-\cos n\, \pi)$ is used only with the first power these formulas give the mutual impedance between one pair of such symmetrically grouped windings and another single group with axis inclined at an angle θ.

The value of self induction is

$$\Delta_1 L_1 = \frac{16\, N_1^2\, r\, e}{10^9\, \pi^2\, d}\, \Sigma \left\{ \frac{1}{n^4} \sin^2 n\, m_0\, \pi \sin^2 n\, m_1\, \pi \right.$$
$$\left. (1 - \cos n\, \pi)^2 \right\} \qquad (17)$$

$\Delta_2 L_1$ is found in the same manner as before

$$L_1 = \Delta_1 L_1 + \Delta_2 L_1 \qquad (18)$$

It is obvious from (**15**) and (**16**) that the effect of dissymmetry is to introduce more or less double frequency into the wave form of generated e. m. f.

It will be seen from an examination of (**15**) and (**17**) that, for example, a winding of pitch $\frac{2\pi}{3}$ and subtending an angle $\frac{\pi}{3}$ when connected in a symmetrical group of two has the same field form and characteristics as a full pitch winding of the same number of turns subtending an angle $\frac{2\pi}{3}$.

There are many symmetrical forms of winding but all will be found to be covered by the formulas (**15**) and (**16**).

Unsymmetrical Windings. These may take many forms which may be classified:

(1) Dissymmetry of flux form due to even harmonics.

(2) Dissymmetry in axial position of polyphase groups.

(3) Dissymmetry in windings due to incorrect grouping of coils.

(4) Dissymmetry due to unsymmetrical magnetic characteristics of the iron.

Of these various forms of dissymmetry the most common is a combination of (**1**), (**2**) and (**3**). These forms of unsymmetrical windings may all be calculated by the formulas (**11**) to (**16**).

It is to be noted that the mutual inductance between a symmetrical and an unsymmetrical winding is harmonically symmetrical. Hence, if the field of a machine is harmonically symmetrical, the e. m. f. generated will be also harmonically symmetrical whatever may be the form of the windings.

The reciprocal nature of M is fully established by its form, for it is immaterial in obtaining (**16**) whether we start out with the winding whose pitch is m_x or with that whose pitch is m_0, the result will be the same. The effect of saturation will be to tend to alter the values of the coefficients of M but the general form will not vary appreciably. We shall now consider some standard windings of Generators and Motors.

Three-Phase Symmetrical Full Pitch. Here m_0, m_1 and m_2 are 0.5, 0.1666 and 0.1666 respectively. Using formula (**15**) all the even harmonics disappear and $(1 - \cos n\,\pi)^2$ is equal to 4 or zero.

$$M_{12} = \frac{16\,N_1\,N_2\,r\,l}{10^9\;\pi^2\,d}\left(\cos\theta + \frac{4}{81}\cos 3\,\theta + \frac{1}{625}\cos 5\,\theta + \frac{1}{2401}\cos 7\,\theta + \frac{4}{6561}\cos 9\,\theta + \ldots\right) \qquad (19)$$

Theoretical Symmetrical Three-Phase Winding. Here $m_0 = 0.5, m_1 = m_2 = 0.333$. Using formula (**11**)

$$M_{12} = \frac{3}{4}\,\frac{16\,N_1\,N_2\,r\,l}{10^9\,\pi^2\,d}\left(\cos\theta + \frac{1}{625}\cos 5\,\theta\right.$$

$$\left. + \frac{1}{2401}\cos 7\,\theta + \frac{1}{14641}\cos 11\,\theta + \;.\;.\;.\right) \qquad (\mathbf{20})$$

Here the third group of harmonics is entirely eliminated.

Three-Phase Symmetrical $\frac{2\,\pi}{3}$ *Pitch Winding.* Here $m_0 =$ $0.333, m_1 = m_2 = 0.166$. Using formula (**15**) .

$$M = \frac{3}{4}\,\frac{16\,N_1\,N_2\,r\,l}{10^9\,\pi^2\,a}\left(\cos\theta + \frac{1}{625}\cos 5\,\theta\right.$$

$$\left. + \frac{1}{2461}\cos 7\,\theta + \frac{1}{14641}\cos 11\,\theta + \;.\;.\;.\;.\right) \qquad (\mathbf{21})$$

which gives the same result as (**20**).

Formulas for Salient Pole Machines

The formulas given in the preceding discussion are appropriate for distributed winding and non-salient poles. Where salient poles are used the field form due to the poles with a given winding will be arbitrary so that with the polar axis as reference we shall have

$$\mathfrak{B} = \frac{2\,\pi\,N_a\,I_a}{d}\,\Sigma\,(A_n\cos n\,\theta) \qquad (\mathbf{22})$$

Where $\mathfrak{B}$ is the induction through the armature or stator. When the poles are symmetrical $A_n \cos n\,\theta$ might be chosen at once for this condition and in this case we do not require coefficients of mutual induction between pole windings, since the value of $\mathfrak{B}$ is obtained by considering the mutual reaction between pole windings to be such as will produce symmetry. We may however assume $\mathfrak{B}$ to be perfectly general in form in which case the flux through a coil of pitch $2\,m_0\,\pi$ is

$$\varphi = \frac{4\,\pi\,N_a\,I_a\,r\,l}{10\,d}\,\Sigma\left(\frac{A_n}{n}\sin n\,m_0\,\pi\cos n\,\theta\right) \qquad (\mathbf{23})$$

We have therefore for the mutual induction between one pole and a group of coils at an angle θ and subtending an angle $2\,m_1\,\pi$

$$M_{a1} = \frac{4\ N_a\ N_1\ r\ l}{10^9\ d}\ \Sigma \left(\frac{A_n}{n^2}\ \sin n\ m_0\ \pi \sin n\ m_1\ \pi \cos n\ \theta \right) \qquad \textbf{(24)}$$

and where there is symmetry due to grouping of windings, we have

$$M_{a1} = \frac{4\ N_a\ N_1\ r\ l}{10^9\ d}\ \Sigma \left\{ \frac{A_n}{n^2}\ \sin n\ m_0\ \pi \sin n\ m_1\ \pi \right.$$

$$\left. (1 - \cos n\ \pi)^2 \cos n\ \theta \right\} \qquad \textbf{(25)}$$

where N_a is the number of turns for one pole and (**25**) applies to one pair of poles and the corresponding group of coils. When there are more than one pair of poles in series and the corresponding groups of winding are also in series, if it is desired to consider the mutual inductance of the complete winding, the result given above must be multiplied by the number of pairs of poles.

If in equation (**16**) we take

$$\left.\begin{aligned} \frac{N_a}{2\ \pi}\ \frac{1}{n} \sin n\ m_a\ \pi &= N_a \\ \text{and} \qquad \frac{1}{\pi\ n} &= B_n \end{aligned}\right\} \qquad \textbf{(26)}$$

it becomes

$$M_{1a} = \frac{32\ N_1\ N_a\ r\ l}{10^9\ d}\ \Sigma \left\{ \frac{B_n}{n^2}\ \sin n\ m_x\ \pi \sin n\ m_0\ \pi \right.$$

$$\left. \sin n\ m_1\ \pi\ (1 - \cos n\ \pi)^2 \cos n\ \theta \right\} \qquad \textbf{(27)}$$

which is the expression corresponding to (**25**) starting with the winding flux form. (**25**) and (**27**) must therefore be identical and we have

$$\frac{32\ N_1\ N_a\ r\ e}{10^9\ d}\ B_n \sin n\ m_x\ \pi - \frac{4\ N_a\ N_1\ r\ e}{10^9\ d}\ A_n$$

or

$$\mathcal{B}_n = \frac{A_u}{8 \sin n\ m_x\ \pi} \qquad \textbf{(28)}$$

and

$$\mathcal{B}_1 = \frac{2\ \pi\ I_1}{10\ d}\ \Sigma\ (B_n \sin n\ m_0\ \pi \cos n\ \theta) \qquad \textbf{(29)}$$

and is the induction wave form for a single turn of the winding.

The expression for the mutual inductance between windings of the same core for salient poles is obtained in terms of the pole flux wave form by substituting in the formulas $\frac{A_n}{8 \sin n\, m_x\, \pi}$ for $\frac{1}{n\,\pi}$. We have therefore the following formulas for salient poles.

General expression considering only one pole and one group of coils.

$$\mathcal{B}_a = \frac{2\,\pi\, N_a\, I_a}{10\, d} \Sigma\, (A_n \cos n\,\theta) \tag{a}$$

$$\mathcal{B}_1 = \frac{\pi\, I_1}{20\, d} \Sigma \left(A_n \frac{\sin n\, m_0\, \pi}{\sin n\, m_a\, \pi} \cos n\,\theta\right) \tag{b}$$

$$M_{a1} = \frac{4\, N_a\, N_1\, r\, l}{10^9\, d} \Sigma \left(\frac{A_n}{n^2} \sin n\, m_0\, \pi \sin n\, m_1\, \pi \cos n\,\theta\right) \tag{c}$$

$$M_{12} = \frac{2\, N_1\, N_2\, r\, l}{10^9\, \pi\, d} \Sigma \left(\frac{A_n}{n^3} \frac{\sin n\, m_0\, \pi}{\sin n\, m_x\, \pi} \sin n\, m_0\, \pi \sin n\, m_1\, \pi \sin n\, m_2\, \pi \cos n\,\theta\right) \tag{d}$$

$$\Delta_1 L_a = \frac{4\,\pi\, N_a^2\, r\, l}{10^9\, d} \Sigma \left(\frac{A_n}{n} \sin n\, m_x\, \pi\right) \tag{e}$$

$$\Delta_1 L_1 = \frac{2\, N_1^2\, r\, l}{10^9\, \pi\, d} \Sigma \left(\frac{A_n}{n} \frac{\sin^2 n\, m_0\, \pi \sin^2 n\, m_1\, \pi}{\sin n\, m_x\, \pi}\right) \tag{f}$$

General expressions considering only poles to be symmetrical. Considered on the basis of two poles, N_a being turns on one pole.

$$\mathcal{B}_a = \frac{2\,\pi\, N_a\, I_a}{10\, d} \Sigma\, \{A_n (1 - \cos n\,\pi) \cos n\,\theta\} \tag{a'}$$

$$\mathcal{B}_1 = \frac{\pi\, I_1}{20\, d} \Sigma \left\{A_n \frac{\sin n\, m_0\, \pi}{\sin n\, m_x\, \pi} (1 - \cos n\,\pi) \cos n\,\theta\right\} \tag{b'}$$

$$M_{a1} = \frac{4\, N_a\, N_1\, r\, l}{10^9\, d} \Sigma \left\{\frac{A_n}{n^2} \sin n\, m_0\, \pi \sin n\, m_1\, \pi (1 - \cos n\,\pi) \cos n\,\theta\right\} \tag{c'}$$

$$M_{12} = \frac{2\,N_1\,N_2\,r\,l}{10^9\,\pi\,d}\,\Sigma\left\{\frac{A_n}{n^3}\;\frac{\sin n\,m_0\,\pi}{\sin n\,m_x\,\pi}\cdot\sin n\,m_0\,\pi\,\sin n\,m_1\,\pi\right.$$

$$\left.\sin n\,m_2\,\pi\,\cos n\,\theta\right\}\text{henrys} \quad (\mathbf{d}')$$

$$\Delta_1\,L_a = \frac{4\,\pi\,N_a^2\,r\,l}{10^9\,d}\,\Sigma\left\{\frac{A_n}{n}\,\sin n\,m_x\,\pi\,(1-\cos n\,\pi)\right\} \quad (\mathbf{e}')$$

$$\Delta_1\,L_1 = \frac{2\,N_1^2\,r\,l}{10^9\,\pi\,d}\,\Sigma\left\{\frac{A_n}{n}\;\frac{\sin^2 n\,m_0\,\pi\,\sin^2 n\,m_1\,\pi}{\sin n\,m_x\,\pi}\right\} \quad (\mathbf{f}')$$

General expression with both polar and winding symmetry.

$$\mathfrak{B}_a = \frac{2\,\pi\,N_a\,I_a}{10\,d}\,\Sigma\,\{A_n\,(1-\cos n\,\pi)\cos n\,\theta) \quad (\mathbf{a}'')$$

$$\mathfrak{B}_1 = \frac{\pi\,I_1}{20\,d}\,\Sigma\left\{A_n\,\frac{\sin n\,m_0\,\pi}{\sin n\,m_x\,\pi}\,(1-\cos n\,\pi)\cos n\,\theta\right\} \quad (\mathbf{b}'')$$

$$M_{a1} = \frac{4\,N_a\,N_1\,r\,l}{10^9\,d}\,\Sigma\left\{\frac{A_n}{n^2}\,\sin n\,m_0\,\pi\,\sin n\,m_1\,\pi\,(1-\cos n\,\pi)^2\right.$$

$$\left.\cos n\,\theta\right\} \quad (\mathbf{c}'')$$

$$M_{12} = \frac{2\,N_1\,N_2\,r\,l}{10^9\,\pi\,d}\,\Sigma\left\{\frac{A_n}{n^3}\;\frac{\sin n\,m_0\,\pi}{\sin n\,m_x\,\pi}\,\sin n\,m_0\,\pi\,\sin n\,m_1\,\pi\right.$$

$$\left.\sin n\,m_2\,\pi\;(1-\cos n\,\pi)^2\cos n\,\theta\right\} \quad (\mathbf{d}'')$$

$$\Delta_1\,L_a = \frac{4\,\pi\,N_a^2\,r\,l}{10^9\,d}\,\Sigma\left\{\frac{A_n}{n}\,\sin n\,m_x\,\pi\,(1-\cos n\,\pi)^2\right\} \quad (\mathbf{e}'')$$

$$\Delta_1\,L_1 = \frac{2\,N_1^2\,r\,l}{10^9\,\pi\,d}\,\Sigma\left\{\frac{A_n}{n}\;\frac{\sin^2 n\,m_0\,\pi\,\sin^2 n\,m_1\,\pi}{\sin n\,m_x\,\pi}\right.$$

$$\left.(1-\cos n\,\pi)^2\right\} \quad (\mathbf{f}'')$$

In using any of the formulas given above for machines having more than two poles, it must be divided by the number of pairs of poles and likewise the expression for M or $\Delta_1\,L$ must be multiplied by the number of pairs of poles, which leaves the formula for these quantities unchanged.

Let us next consider the actual induction in the air gap with a distributed winding operating with three-phase currents. Let i_{m1} be the magnetizing current of the first phase i_{m2} and i_{m3} those of the other phases. The induction due to one group of coils of phase 1 is

$$\mathfrak{B}_1 = \frac{8\, N_1\, i_{m1}}{10\, \pi\, d}\, \Sigma \left\{ \frac{1}{n^2} \sin n\, m_0\, \pi \sin n\, m_1\, \pi \cos n\, \theta \right\} \qquad \textbf{(30)}$$

and if the phase displacement of 2 and 3 from 1 be φ_{12} and φ_{13}

$$\mathfrak{B}_2 = \frac{8\, N_2\, i_{m2}}{10\, \pi\, d}\, \Sigma \left\{ \frac{1}{n^2} \sin n\, m_0\, \pi \sin n\, m_2\, \pi \cos (n\theta - \varphi_{12}) \right\} \qquad \textbf{(31)}$$

$$\mathfrak{B}_3 = \frac{8\, N_3\, i_{m3}}{10\, \pi\, d}\, \Sigma \left\{ \frac{1}{n^2} \sin n\, m_0\, \pi \sin n\, m_2\, \pi \cos (n\, \theta - \varphi_{13}) \right\} \qquad \textbf{(32)}$$

For symmetrically grouped coils the formulas become

$$\mathfrak{B}_1 = \frac{8\, N_1\, i_{m1}}{10\, \pi\, d}\, \Sigma \left\{ \frac{1}{n^2} \sin n\, m_0\, \pi \sin n\, m_1\, \pi\, (1 - \cos n\, \pi) \cos n\, \theta \right\} \qquad \textbf{(33)}$$

$$\mathfrak{B}_2 = \frac{8\, N_2\, i_{m2}}{10\, \pi\, d}\, \Sigma \left\{ \frac{1}{n^2} \sin n\, m_0\, \pi \sin n\, m_2\, (1 - \cos n\, \pi) \cos m\, (\theta - \phi_{12}) \right\} \qquad \textbf{(34)}$$

$$\mathfrak{B}_3 = \frac{8\, N_3\, i_{m3}}{10\, \pi\, d}\, \Sigma \left\{ \frac{1}{n^2} \sin n\, m_0\, \pi \sin n\, m_3\, \pi\, (1 - \cos n\, \pi) \cos m\, (\theta - \varphi_{13}) \right\} \qquad \textbf{(35)}$$

For a symmetrical three-phase motor with full pitch coils $m_0 = 0.5$, $m_1 = m_2 = m_3 = 0.166$ (**33**), (**39**) and (**35**) become of the four

$$\mathfrak{B}_1 = \frac{8\, N_1\, i_{m1}}{10\, \pi\, d} \left\{ \cos \theta - \frac{2}{9} \cos 3\, \theta + \frac{1}{25} \cos 5\, \theta + \frac{1}{49} \cos 7\, \theta - \frac{2}{81} \cos 9\, \theta + \frac{1}{121} \cos 11\, \theta + \frac{1}{169} \cos 13\, \theta + \right\} \qquad \textbf{(36)}$$

which is the field due to one group of coils alone. The wave is flattened by the third group of harmonics but all the other harmonics are peaking values. There is therefore a decided gain in such a wave form of flux since it permits of high fundamental flux density.

The maximum value of flux is approximately

$$B_{max} = 0.823 \cdot \frac{8\, N_1\, i_m}{10\, \pi\, d} \text{ gaus} \tag{37}$$

where d is given in centimeters.

$$B_{max} = \frac{1.67\, N_1\, i_m}{\pi\, d} \quad \text{maxwells per square inch,}$$

with d given in inches.

For the total winding the resultant induction will be the sum of B_1, B_2, and B. If we take the symmetrical winding with angles between planes of symmetry

$\varphi_{12} = \frac{2\,\pi}{3}$ and $\varphi_{13} = \frac{4\,\pi}{3}$, we have

$$\left.\begin{aligned} \cos n\,\theta &= \frac{e^{jn\theta}}{2} + \frac{e^{-jn\theta}}{2} \\ \cos n\left(\theta - \frac{2\,\pi}{3}\right) &= a^{-n}\,\frac{e^{jn\theta}}{2} + a^{n}\,\frac{e^{-jn\theta}}{2} \\ \cos n\left(\theta - \frac{4\,\pi}{3}\right) &= a^{n}\,\frac{e^{jn\theta}}{2} + a^{-n}\,\frac{e^{-jn\theta}}{2} \end{aligned}\right\} \tag{38}$$

If we multiply these three quantities successively by $\dot{I}_{m1}$, $a^2\dot{I}_{m1}$, $a\dot{I}_{m1}$ and add, we have

$$\dot{I}_{m1}\left\{\frac{e^{jn\theta}}{2}\left(1 + a^{-(n-2)} + a^{(n+1)}\right)\left(+ \frac{e^{-jn\theta}}{2} \times \left(1 + a^{n+2} + a^{-(n-1)}\right)\right)\right\} \tag{39}$$

and giving n successive odd values from 1 up, we find for (**39**) the following values

$n = 1$ (**39**) becomes $\frac{3}{2}\,\dot{I}_{m1}\,e^{-j\theta}$

$n = 3$ " " 0

$n = 5$ " " $\frac{3}{2}\, \bar{I}_{m1}\, e^{j5\theta}$

$n = 7$ " " $\frac{3}{2}\, \bar{I}_{m1}\, e^{-j7\theta}$

$n = 7$ " " 0

$n = 11$ " " $\frac{3}{2}\, \bar{I}_{m1}\, e^{j11\theta}$

$n = n$ " " $2\, \bar{I}_{m1} \sin^2 \frac{2\,n\,\pi}{3}\, e^{-j\frac{2}{\sqrt{3}} \sin \frac{2\,n\,\pi}{3}\, n\,\theta}$

We may therefore express $\mathcal{B}$ by
$\mathcal{B}$ = real part of

$$\frac{16\, N_1\, \bar{I}_{m1}}{10\,\pi\, d}\, \Sigma \left\{ \frac{1}{n^2} \sin n\, m_0\, \pi \sin n\, m_1\, \pi\, (1 - \cos n\,\pi) \right.$$

$$\left. \times \sin^2 \frac{2\,n\,\pi}{3}\, e^{-j\frac{2}{\sqrt{3}} \sin \frac{2\,n\,\pi}{3}\, n\,\theta} \right\} \qquad (40)$$

It will be obvious that if we proceed around the cylinder in the negative direction of rotation at an angular speed w and $\bar{I}_{m1}$ is equal to $I_{m1}\, e^{jwt}$, for $n = 1$ the value of B_1 will remain constant and real, hence B_1 must be a constant field rotating at angular velocity w in the negative direction. The value of B may be expressed in harmonic form, but in this form it does not illustrate the rotating field theory so aptly. The harmonic form is given below and is simpler in appearance than (**40**).

$$\mathcal{B} = \frac{16\, N_1\, i_{m1}}{10\,\pi\, d}\, \Sigma \left(\frac{1}{n^2} \sin n\, m_0\, \pi \sin n\, m_1\, \pi\, (1 - \cos n\,\pi) \right.$$

$$\left. \sin^2 \frac{2\,n\,\pi}{3} \cos n\,\theta \right) \qquad (41)$$

For a symmetrical three-phase motor with full pitch coil $(m_0 = 0.5\, m_1 = 0.166)$ $\mathcal{B}$ becomes

$$\mathcal{B} = \frac{12\, N_1\, i_{m1}}{10\,\pi\, d}\, \Sigma \left\{ \cos\theta + \frac{1}{25} \cos 5\,\theta + \frac{1}{49} \cos 7\,\theta \right.$$

$$\left. + \frac{1}{121} \cos 11\,\theta + \frac{1}{169} \cos 13\,\theta + \ldots \right\} \qquad (42)$$

This gives for the maximum induction approximately

$$\mathcal{B}_{max} = \frac{1.075 \times 12\, N_1\, i_{m1}}{10\, \pi\, d} = \frac{1.29\, N_1\, i_m}{\pi\, d} \text{ gauss} \qquad (43)$$

where d is measured in centimeters.

$$\mathcal{B}_{max} = \frac{3.28 \times N_1\, i_{m1}}{\pi\, d} \text{ maxwell per square inch} \qquad (44)$$

where d is measured in inches and N is the total number of turns per pair of poles.

REPORT OF THE BOARD OF DIRECTORS

FOR FISCAL YEAR ENDING APRIL 30, 1918

The Board of Directors of the American Institute of Electrical Engineers presents herewith to the membership its Thirty-fourth Annual Report, for the fiscal year ending April 30, 1918. A General Balance Sheet showing the condition of the Institute's finances on April 30, 1918, together with other detailed financial statements, is included herein.

Directors' Meetings.—The Board of Directors held ten regular meetings during the year and one adjourned meeting. Eight meetings were held in New York, one in Philadelphia in October, and one in Cleveland in March. The adjourned meeting was held in New York in March.

The Executive Committee held two meetings in New York, on January 5 and January 22, 1918. Both of these meetings were held for the purpose of considering matters relating to the Engineering Council.

In accordance with the practise established years ago, the Board has endeavored to keep the membership informed of its proceedings by the monthly publication of a résumé of the business transacted at each meeting. These notices have appeared in each issue of the PROCEEDINGS, but they are not, however, a complete report of the work done by the Board at any one meeting, for the reason that many important matters are referred to committees for further consideration, and publicity in such cases must generally be deferred pending their final disposition. Information relating to such matters is usually published in subsequent issues.

Annual Meeting.—The Annual Business Meeting was held at Institute headquarters, New York, on May 18, 1917. The Annual Report of the Board of Directors for the fiscal year ending May 1, 1917, was presented as published in full in the June 1917 issue of the PROCEEDINGS. The Tellers Committee presented its report upon the election of officers for the year beginning August 1, 1917.

The principal feature of the meeting was the presentation of the Edison Medal to Nikola Tesla; this ceremony following the business meeting.

Annual Convention.—The Thirty-fourth Annual Convention was originally scheduled to be held at Hot Springs, Va., June 26-29, 1917. In view of the national crisis which developed in April it was decided by the Board of Directors at the May meeting to cancel the Convention and to hold instead a special meeting in New York City, for the presentation of

the papers originally scheduled for presentation at the Convention. This special meeting was held on June 27-28.

Pacific Coast Convention.—The Pacific Coast Convention for 1917 was to have been held under the auspices of the Los Angeles Section in September 1917. At the May meeting of the Board of Directors, upon the recommendation of the Los Angeles Section and the Meetings and Papers Committee, the Convention was cancelled.

Philadelphia Meeting.—The first Institute meeting of the administrative year of 1917-18 was held in Philadelphia on October 8, 1917. There were two technical sessions, at which three papers were presented.

Three-City Meeting.—A Three-City Meeting was held in Boston, January 8, New York, January 11, and Chicago January 14, 1918, the same paper being presented at all three meetings. This innovation was tried for the purpose of providing an opportunity for the local members in all three cities to participate in the discussion, all of which will be published in the TRANSACTIONS.

Midwinter Convention, New York.—The Sixth Midwinter Convention was held in New York on February 15 and 16, 1918. Four technical sessions were held. The attendance was about 400. On the evening of February 15 an informal dinner was held which was attended by 225 members and guests.

Cleveland Meeting.—An inter-section meeting in which the Toledo, Toronto, Detroit, Pittsburgh and Cleveland Sections participated, was held in Cleveland, Ohio, on March 8, 1918. Four technical papers were presented at two technical sessions. An informal dinner was held between the afternoon and evening sessions. The latter session being held jointly with the Association of Iron and Steel Electrical Engineers, one of the four papers was presented on behalf of the A. I and S. E. E. The meeting was attended by Presidents E. W. Rice, Jr., of the A. I. E. E., and C. A. Mink, of the A. I. and S. E. E., and members were present from all the sections mentioned above. The attendance at this meeting was about 150.

Pittsburgh-New York Meeting.—The Institute meeting for April was held in Pittsburgh on April 9 and in New York on April 12, under an arrangement similar to the meetings held in Boston, New York and Chicago in January 1918. The same two papers were presented at both the New York and Pittsburgh meetings.

New York Meetings.—In addition to the meetings referred to above, Institute meetings were also held in New York in November and April. The attendance at the November meeting was 175 and one paper was presented; the attendance at the April meeting was 250 and two papers were presented. The April meeting was preceded by an informal buffet supper under the auspices of the New York Membership Acquaintance committee.

National Defense.—In the annual reports for 1916 and 1917 the published references to the Institute's connection with matters pertaining to National Defense were limited to the various actions taken during the year covered by each report. It has been thought, in view of the entry of the United States into the war, that the membership will gain a better perspective of the services actually rendered by the Institute if in preparing the present report there be included not only a record of the developments of the past year, but a summary of all of the defense work done during the three years from the time when the co-operation of the engineering societies was first suggested in connection with national preparedness. It is felt that such a statement will also be useful as a record for future reference, and the following has been prepared with these objects in view.

Engineer Officers' Reserve Corps.—Early in 1915, when the subject of an Officers' Reserve Corps in connection with the Army reorganization plan was under consideration in Congress, the suggestion was made that the National Engineering Societies tender their assistance to the War Department in the formation of an Engineer Reserve, there being no adequate provision at the time for any large body of engineers in the Army. Acting on this suggestion the Institute and other national engineering societies formed a joint committee for the purpose of taking such steps as seemed desirable to assist in the organization of such a corps as a part of the regular Army. Conferences were held with the Secretary of War, officers of the General Staff and the War College, and the chairmen of the House and Senate Committees on Military Affairs. Largely as a result of the work of this joint committee, the National Defense Act of 1916, which became effective on July 1st of that year, embodied a provision for an Engineer Reserve Corps as part of the Officers' Reserve Corps. A circular containing an abstract of the engineer section of this Act was mailed to all members of the Institute on July 5, 1916.

Upon completion by the War Department of the details of the requirements and qualifications for commissions in the Officers' Reserve Corps as provided in the new law, a second circular was issued by the Institute to the membership under date of September 12, 1916, giving complete information regarding the qualifications for commissions in the Reserve, thus enabling interested members to apply for commissions promptly. Many applications were filed at that time by members of the Institute who are now in active service.

Naval Consulting Board.—In July 1915 the Institute was invited by the Honorable Josephus Daniels, Secretary of the Navy, to select two members for appointment by him upon a proposed Naval Advisory Board, to be presided over by Mr. Thomas A. Edison, and to be composed of men recognized throughout the country for their inventive genius and engineering achievements, to assist the Navy Department, instructively and critically, in the development of such new ideas for naval advance as might be found worthy of consideration. The underlying idea was to make available to the Navy Department the latent inventive and engineering genius of the country to improve the Navy and to bring the officers of the service into more intimate contact with the industrial resources of the

country. Similar invitations were extended to ten other scientific and engineering organizations.

Industrial Inventory.—The good work of the Institute's representatives upon the Naval Consulting Board is attested to in the following letter and invitation received by the Institute from the President of the United States, under date of January 13, 1916:

"The White House
Washington. January 13, 1916.

My dear Sir:

The work which the American Institute of Electrical Engineers has done through its members on the Naval Consulting Board is a patriotic service which is deeply appreciated. It has been so valuable that I am tempted to ask that you will request the Institute to enlarge its usefulness to the Government still further by nominating for the approval of the Secretary of the Navy a representative from its membership for each state in the Union to act in conjunction with representatives from the American Society of Mechanical Engineers, the American Society of Civil Engineers, the American Chemical Society, and the American Institute of Mining Engineers, for the purpose of assisting the Naval Consulting Board in the work of collecting data for use in organizing the manufacturing resources of the country for the public service in case of emergency. I am sure that I may count upon your cordial cooperation.

With sincere regard,

Cordially yours,
(Signed) WOODROW WILSON.

Mr. John J. Carty, President,
American Institute of Electrical Engineers,
New York City."

This invitation was accepted by the Board of Directors of the Institute at a special meeting called on January 21, 1916, and the nominees selected by the Institute were subsequently appointed by the Secretary of the Navy. The resulting organization became officially known as the *State Directors of the Organization for Industrial Preparedness and Associate Members of the Naval Consulting Board of the United States.* These State Directors made a canvass of all the industrial establishments in their respective states by means of a confidential industrial inventory form giving in great detail data regarding their manufacturing and producing resources. The statistics obtained by the Government as the result of this work fully justified the confidence shown by the President of the United States in entrusting to engineers a task of such magnitude and detail.

General Co-operation with Government.—On February 5, 1917, during the diplomatic exchanges between the American and German Governments, resulting from the announced policy of the latter to sink merchant shipping in certain prescribed zones without warning, the following joint telegram, signed by the Presidents of the Civil, Mining, Mechanical and Electrical Engineers, was sent to the President of the United States:

"To the President,
Executive Mansion,
Washington, D. C.

We, the presidents of the National Societies of Civil, Mining, Mechanical and Electrical Engineers, and of the United Engineering Society, with a membership of thirty thousand,

cordially unite in supporting Congress and the Administration in the stand for freedom and safety on the seas, and we are confident that we represent the membership of the four societies in offering to assist toward the organization of engineers for service to our country in case of war."

This was followed by a special meeting of the Executive Committee on February 6, at which it was decided to issue immediately, on behalf of the Board of Directors, to all Institute members in the United States, a circular letter calling attention to this telegram and to the opportunities existing for patriotic service to the nation in case of emergency. This circular letter was issued under date of February 8, 1917, and was accompanied by a simple classification sheet which members were requested to fill out and return to Institute headquarters, indicating whether or not they would be available for military or naval service if required. Over two thousand of these classification sheets were filled out and returned to Institute headquarters and subsequently were placed at the disposal of the War Department. A considerable number of the members who sent in data sheets was communicated with by the branches most urgently in need of their services.

On April 2, 1917, in co-operation with several other engineering societies, the Institute issued to the membership two pamphlets containing instructions and methods of procedure for engineers who desired to offer their services in the Army or Navy of the United States. The pamphlets also contained all information available regarding all of the branches of the Army and Navy in which the services of electrical engineers could be utilized to good advantage. The circulation of these pamphlets aroused great interest and resulted in the filing of a great many more applications by Institute members for commissions in the Officers' Reserve Corps and in the Naval Reserve, many of which were favorably acted upon.

During the past year the Institute has maintained its connection with the Government through a number of agencies, among which may be mentioned: the Naval Consulting Board, the Subcommittee on Wires and Cables of the Standards Committee, the National Research Council, the Engineering Council, and the General Engineering Committee of the Advisory Commission of the Council of National Defense.

Personnel.—In the work of obtaining technically trained men and men of special qualifications for Government service, the Institute has been able to render considerable assistance to the Government. It has been called upon repeatedly by various branches of the Army, and the Navy for technical men for special services, also by industrial corporations and various Government bureaus, to recommend individuals or small groups of men for special work.

On September 20, 1917, Rear-Admiral L. C. Palmer, Chief of the Bureau of Navigation, Navy Department, in a letter addressed to the President of the Institute, informed him that the Secretary of the Navy had authorized the commissioning of one hundred graduate electrical engineers as Lieutenants, junior grade, in the U. S. Naval Reserve Force, that three organizations, namely, the Naval Consulting Board, the National Research Council and the American Institute of Electrical Engineers, were each requested to nominate eighty-five men possessing certain specified

qualifications, and that from the total of two hundred and fifty-five candidates thus nominated, a Board of Naval Examiners would select the one hundred men to be commissioned. A circular containing this information was mailed to the entire membership of the Institute in the United States, so that every member might have an opportunity to apply for one of these commissions or to recommend desirable candidates.

At the Directors meeting held on October 8, 1918, a special committee was appointed to examine the applications received by the Secretary and to select therefrom the Institute's eighty-five nominees. This committee, consisting of five members of the Board of Directors, met at Institute headquarters on October 16 and 17, and from the applications received up to that date, selected, solely upon their merits, eighty-five nominees whose names were transmitted to Rear-Admiral Palmer on October 18. The Naval Consulting Board and the National Research Council transmitted their nominations upon the same date.

Of the eighty-five men nominated by the Institute, thirty-eight were included in the first hundred commissioned. It was learned later from reports received from individual members of the Institute that in addition to the one hundred men who were originally commissioned a considerable number of other applicants received commissions.

Under date of March 22, 1918, the Institute was requested by Rear-Admiral Palmer to nominate, in groups of twenty-five each, specially qualified electrical engineers, for training as submarine officers in the Naval Reserve Force. The successful candidates are to be commissioned as Ensigns, and after satisfactorily completing a special technical course of instructions they will become part of the active Submarine Officer Complement of the Navy. The first group of nominations was submitted to the Navy Department, early in April.

This request was supplemented several weeks later with a call for an additional 50 nominees for the rank of Ensign in general service in the Naval Reserve Force. Work on the selection of these nominees is now progressing.

Other requests received by the Institute for co-operation in obtaining the services of technical men include the following:

Navy Department: Bureau of Navigation, candidates for aviation inspection duty for training as Ensigns in the Naval Reserve Flying Corps; Bureau of Yards and Docks, candidates for appointment in the Civil Engineer Corps of the Naval Reserve Force, for the ranks of Ensign, Lieutenant (junior grade) and Lieutenant.

Bureau of Chemistry: electrical engineers for special investigations in grain-dust explosions in mills throughout the country.

War Department: Signal Corps, electrical men for radio division, radio operators and mechanicians for Air Service, and graduate electrical engineers for the aviation section; Coast Artillery Corps, electrical graduates for training school at Ft. Monroe, Va. with opportunity for commissions; Ordnance Department, Trench Warfare Section, technical men for commissions in Ordnance Officers Reserve Corps; Corps of Engineers, enlisted men for engineering and railway units and replacement regiments of engineers.

Eight hundred and twenty-four members of the Institute are now serving with the uniformed forces in the Army or Navy of the United States, and in addition, a large number are serving the Government in various civilian capacities. A great many members are also giving their services as members of various committees engaged in war activities.

General Engineering Committee.—Shortly after the entry of the United States into the war and at the suggestion of President Wilson, each of the four National Engineering Societies designated two representatives upon a committee of the Advisory Commission of the Council of National Defense under Dr. Hollis Godfrey, Commissioner of Engineering and Education, as chairman, to serve as the medium through which the engineering societies might serve the Government. In September last this committee was reorganized as the "General Engineering Committee," with Prof. C. A. Adams as chairman.

Besides acting on minor questions referred to it by the Government, this committee was active on four important tasks: 1. the preparation of a scheme of organization for war purchases, which has since partly been put into operation; 2. electric welding in shipbuilding; 3. development of cast steel anchor chain; 4. specifications for shipboard cable for the Navy Department. (For details regarding the three latter items see statement herein relating to the Standards Committee.)

The General Engineering Committee dissolved when the Council of National Defense discontinued all of its advisory committees. The work was then reorganized and continued under other agencies.

National Research Council.—The National Research Council was formed at the request of the President of the United States by the President of the National Academy of Sciences for the purpose of furthering scientific research in its broadest aspects. Its field includes educational institutions, technical, scientific and medical organizations, governmental departments and the industries. Upon invitation the Institute designated representatives upon the Engineering Committee of the Council. This committee was organized early in 1917 with offices in Washington and New York. It is in contact with the work of the other committees of the Council and since its organization it has been engaged on a wide range of engineering problems brought to its notice by the several branches of the Government. Weekly meetings have been held and weekly reports of its activities have been sent to each member of the committee. The confidential nature of these reports and of the problems which have been under consideration has rendered it inexpedient to publish detailed statements regarding the work which has been carried on.

Membership Service Classification.—Early in February 1917 the Institute offered its services to the Government in case of emergency. It soon became evident that in order to extend the fullest possible cooperation and to respond promptly and effectively to the numerous demands which were being made upon the Institute by the different governmental departments and industrial establishments engaged in Government work, for technical men of special qualifications, it would be necessary to have available for immediate reference at Institute headquarters de-

tailed information regarding the many members who were willing and anxious to serve the Government. After conferences with the other National Engineering Societies, the matter was brought to the attention of the Board of Directors of the Institute at its meeting of October 8, 1917, at which meeting a proof of a suggested form of questionnaire which had been prepared was submitted with a request for an appropriation sufficient to distribute the form to the membership and to compile an index of the replies. Recognizing the importance of such a classification, the Board granted an appropriation of $1,000 for this purpose and authorized the Secretary to proceed with the work after opportunity had been given for final revision of the form. A special committee was appointed to have supervision of the classification and indexing.

Although primarily intended as an aid in selecting technical men for service in the present emergency, it is proposed to maintain a permanent file of this data at Institute headquarters to be revised from year to year for use after peace has again been restored. Such a classification has been contemplated for several years in connection with the regular work of the Institute and its committees.

Employment.—It is over three years since the Institute first initiated the plan for assisting its members in obtaining employment and employers in obtaining desirable employees. It has not attempted to conduct an employment department in the generally accepted sense of the term, but has simply acted as a medium for placing men in touch with opportunities, through the publication of announcements in the montly Institute PROCEEDINGS, under the heading of "Engineering Service Bulletin."

While the service might have been developed to a greater extent had it been possible to appropriate funds for carrying on the work, the results attained since the plan was inaugurated are, nevertheless, very gratifying. There is no doubt that it offers a wide sphere of usefulness, and that the service is highly appreciated; not only by the individual member who is seeking a position, but also by the many corporations and men in posts of responsibility who have been assisted by the Institute in obtaining the services of high-class technical men. The co-operation of the membership in bringing vacancies to the attention of the Secretary will be very helpful in the future successful conduct of this work.

United Engineering Society.—In the Directors' Annual Report for 1917 reference was made to the addition of three stories to the Engineering Societies Building as a result of an agreement whereby the American Society of Civil Engineers was to be admitted into the fraternity of founder societies and take up its headquarters in the building.

Full details regarding this agreement were published in the PROCEEDINGS for September 1916.

This work was completed in the Fall of 1917 and on December 7, 1917, a joint meeting was held under the auspices of the Institute, the American Society of Mechanical Engineers, and the American Institute of Mining Engineers, at which the American Society of Civil Engineers was formerly welcomed into the fraternity of the founder societies and the occupancy of its quarters in the enlarged Engineering Societies Building. These

four great National Engineering Societies are thus brought together under one roof with all of the obvious advantages for closer cooperative action, realizing more fully the purpose of the donor of the building, Mr. Andrew Carnegie, that it should be the home and headquarters of the engineering profession of America.

Engineering Council.—The Engineering Council represents the result of an organized effort inaugurated in the latter part of 1916 by four of the leading national engineering societies—the American Society of Civil Engineers, American Society of Mechanical Engineers, American Institute of Mining Engineers and the American Institute of Electrical Engineers, to establish a central body to deal with matters of common interest to engineers and to serve as a connecting medium between the engineer on the one hand and the public welfare on the other so far as such matters relate to the engineering profession, in order that united action may be possible.

The first meeting of the Council was held on June 27, 1917. The Annual Meeting of the Council was held on February 21, 1918. Officers were elected and the following committees were appointed: Executive, Finance, Rules, Public Affairs, American Engineering Service, War, Fuel Conservation and Patents.

For details regarding future plans of the Council, its field, and aims, members are referred to the abstracts from a statement issued by the Council in February 1918, published in the Institute PROCEEDINGS for April 1918.

Sections Committee.—The encroachment of the many demands of these unprecedented times has been reflected in the activities of the Sections and Branches. Many of the leading men have been called away on war duties, while others have assumed additional burdens at home. The number of meetings held during the past year has for these reasons been reduced, yet it is gratifying to observe that the total attendance in the Section meetings has actually increased.

This is undoubtedly due to the fact that these meetings have been arranged to present topics of current interest. It has been evident to any one who has seen the notices of these various meetings over the country that the thought of service and knowledge of present day problems were uppermost in the mind of the engineer.

The list of Sections has been increased by the addition of Erie, Pa., which qualified on January 11, 1918, under conditions which inspire confidence in its future.

The Branches have, however, been severely affected by the influences of war. There our young engineers have forfeited their present educational advantages and have gone into the ranks of the service in large numbers. Several Branches have suspended activity, temporarily, while two, the Queens University Branch, Kingston, Ontario, and the Michigan Agricultural College Branch, East Lansing, Michigan, were added, respectively, on January 11 and March 15, 1918. Two other Branches, the Iowa State College Branch, and the Rhode Island State College

Branch, were terminated by the Board of Directors at their request. The tabulation following shows the reduction in Branch activity.

	For Fiscal Year Ending					
	May 1 1913	May 1 1914	May 1 1915	May 1 1916	May 1 1917	May 1 1918
Sections						
Number of Sections.........	29	30	31	32	32	34
Number of Section meetings held....................	244	233	246	251	265	245
Total Attendance...........	22,825	22,626	23,507	28,553	31,299	34,614
Branches						
Number of Branches........	47	47	52	54	59	59
Number of Branch meetings held....................	357	306	328	360	368	268
Attendance................	11,808	11,617	12,712	15,166	16,107	10,683

On the whole the situation in the Sections and Branches is one for encouragement rather than otherwise. It augurs well for the participation of the engineer in the country's large affairs and insures the continued maintenance of the activities of the Institute.

Standards Committee.—The Standards Committee has held monthly meetings throughout the year except in January and the summer months.

Owing to the numerous demands made upon many members of the committee by war work, all non-essential subcommittees were allowed to mark time thus reducing the number of active subcommittees from over 40 to about 20.

Subcommittee on Wires and Cables.—The Subcommittee on Wires and Cables of the Standards Committee was appointed by the Board of Directors in response to the request of Rear-Admiral Griffith, Chief of the Bureau of Steam Engineering, to assist the Navy Department in the solution of problems relating to wires and cables with special reference to the high-tension cables to be used on the new electrically-driven warships.

This committee, after conducting a considerable number of investigations and much experimental research, has sent reports to the Navy Department on several subjects. The committee is still co-operating with the Navy Department and expects to extend its activities to other departments of the Government.

Electric Welding in Ship Construction. Another important piece of war work which originated in the Standards Committee is the application of electric welding to shipbuilding. This was started in August 1917 as the Electric Welding Subcommittee of the Standards Committee, and was adopted by the General Engineering Committee of the Council of National Defense in September. Finally, after the Council of National

Defense had dropped all of its advisory committees, this subcommittee was appointed in February by the U. S. Shipping Board, Emergency Fleet Corporation, as its Electric Welding Committee, with C. A. Adams as chairman and with ample financial support. An enormous amount of valuable work has been and is being done by this committee, which includes representatives of: The Emergency Fleet Corporation, the Classification Societies, (Lloyds Register of Shipping and the American Bureau of Shipping), U. S. Navy, Bureau of Standards, electric welding manufacturers and users, electrical engineers and metallurgists.

The Research Subcommittee of the Electric Welding Committee is also attached to the Engineering Division of the National Research Council.

The principal object of the Electric Welding Committee is to save time, labor, material and expense by the extension of the application of electric welding to shipbuilding. This is being done not only by the extension of the application to minor parts of ships, but also by demonstrating its suitability and economy on the capital parts of ships.

British Conference. As a result of an invitation from the Engineering Standards Committee of Great Britain, Mr. H. M. Hobart was sent to London in September 1917 as a delegate from the Standards Committee to a joint conference on standards for electrical machinery. Mr. Hobart brought back numerous suggestions which have been acted upon by the Standards Committee.

Mr. Hobart also investigated the electric welding situation in England and rendered a report which has proved very satisfactory in the work of the Electric Welding Committee.

Another result of this visit was that the Emergency Fleet Corporation, engaged Captain James Caldwell, in charge of the electric welding work for the British Admiralty, to spend a couple of months here and to give the Electric Welding Committee the benefit of the experience of Great Britain. This visit has proved most helpful all around.

Standardization Rules. The result of the year's work of the Standards Committee as far as the Standardization Rules are concerned, does not involve many radical changes, although some of the additions are distinctly valuable. The changes and additions will be published in a revised supplement. A complete revision of form and arrangement is under way and will be completed for a new edition in 1919.

American Engineering Standards Committee.—In January 1917 a joint committee was appointed with three representatives from each of the Four National Engineering Societies, and the American Society for Testing Materials, to prepare a plan of organization for an American Engineering Standards Committee. This committee completed its work on June 19, 1917, and rendered its report to the five societies interested.

The governing boards of the four National Engineering Societies, A. S. C. E., A. S. M. E., A. I. M. E., and A. I. E. E., approved the plan of organization and appointed three representatives each upon the proposed American Engineering Standards Committee. The executive committee of the A. S. T. M., presented certain suggestions and additions. The organization committee was therefore continued and proceeded to consider the suggestions of the A. S. T. M.

A revision of the constitution and rules of procedure governing the proposed American Engineering Standards Committee, satisfactory to the representatives of all the societies, has finally been completed and a report has been submitted to the governing boards of the respective societies for approval.

Meetings and Papers Committee.—The Meetings and Papers Committee has held six monthly meetings during the past year, at which the programs of the Institute meetings and conventions during the season were arranged. One meeting was held in Philadelphia in October 1917, four in New York during the winter, and one in Cleveland in March 1918.

The policy of the Institute of holding a number of its regular monthly meetings outside of New York City was thoroughly discussed at the opening meeting and while there was considerable sentiment in favor of continuing this policy as in the previous year, the difficulty of railroad travel and the fact that the present year was an extremely busy one for a large proportion of the Institute membership led the committee to limit the meetings outside of New York to two; one of which was held in Philadelphia in October, and the other in Cleveland in March.

About 80 papers have been considered by the committee during the year and owing to the abnormally high cost of printing and publishing at the present time the selection of papers has been made with unusual care. Every paper which has been offered during the past year has been reported upon by one or two members of the technical committee to which it belonged before final action has been taken by the Meetings and Papers Committee.

In order to bring the papers presented at regular meetings before as large a number of the Institute members as possible, a new arrangement for meetings has been devised which has been called Inter-section Meetings, in which one paper is presented as nearly simultaneously as possible before several different Sections. Two of these meetings have been held this year with considerable success; one in January 1918 in Boston, New York and Chicago, and another in April in Pittsburgh and New York. The meeting at Cleveland was held under the joint auspices of the Cleveland, Pittsburgh, Toledo, Toronto and Detroit Sections, and a joint technical session was held with the Association of Iron and Steel Electrical Engineers. This participation by the different Sections in regular Institute meetings is believed to have added considerable stimulus to the activities of the Sections participating and has been generally beneficial to the Institute.

Editing Committee.—The Editing Committee, which now has entire supervision of the TRANSACTIONS, announced last year that future issues of TRANSACTIONS would be published semi-annually. Owing to war considerations, however, which resulted in a considerable reduction in the amount of material published, it was found that the papers for the entire year would make only one volume of the usual size and it was subsequently decided to publish the 1917 TRANSACTIONS in one volume. This plan was followed to avoid the publication of two small books instead of one of the usual size, and it also results in a very considerable reduction in the expense of binding and distribution.

The volume is now completed and is being distributed approximately five months earlier than in previous years.

The system of handling papers and discussions for the TRANSACTIONS has been gradually evolved from experience with different methods. It has now been practically standardized for several years and appears to meet with general satisfaction.

All authors and discussors have the opportunity of revising their contributions both in the manuscript of the stenographer and in the proof. Each author has the privilege of reading the proof of all discussion before the final revision of his closure.

All papers published in the PROCEEDINGS are not necessarily published in the bound TRANSACTIONS. The responsibility for a decision in this matter now rests with the Editing Committee.

The committee suggests that papers of the character that are accepted for publication without presentation be printed only in the Annual TRANSACTIONS.

Public Policy Committee.—The Public Policy Committee held one formal meeting during the year at which a communication regarding the bill to incorporate the American Academy of Engineers, referred to the committee by a vote of the Board of Directors, was considered. A report upon this matter was subsequently made to the Board of Directors by the committee.

A majority of the members of the Public Policy Committee, being members also of the Engineering Council, official action by the committee on matters other than that above referred to has not seemed desirable, as such matters now come within the scope of the Engineering Council, thus resulting in a large measure in cooperation between the four National Engineering Societies.

Code Committee.—The Code Committee has continued to represent the Institute on the Electrical Committee of the National Fire Protection Association and representatives of the committee attended the biennial meeting of the National Fire Protection Association. The name of this committee was recently changed by an amendment to the by-laws of the Institute from "Code Committee" to "Committee on Safety Codes."

U. S. National Committee, International Electrotechnical Commission.—Two meetings were held by this committee during the year, both at Institute headquarters; the first on December 14, 1917, the second on March 13, 1918, the latter meeting being held jointly with the Institute's Standards Committee.

The International Electrotechnical Commission has been prevented by the War from holding any international gathering, but it has been the expressed desire of the U. S. National Committee that an attempt should be made to hold such a meeting as soon as conditions will permit, as the lack of intercommunication between the various national committees of the allied countries since 1913 has naturally served to retard generally electrotechnical development.

At the March meeting attention was given to certain inquiries made by the French National Committee concerning such changes as may have

taken place in the A. I. E. E. Standardization Rules since the last convention of the International Electrotechnical Commission in 1913. The necessity for such explanations would not have arisen if the work of the Commission had not been held in abeyance by the world-war. Some progress, however, has been made independently among the various individual national committees.

Committee on Code of Professional Conduct.—The only matter which this committee acted upon during he year was the formulation of definitions of an "Electrical Engineer." A report embodying several definitions has been prepared and filed at Institute headquarters.

Board of Examiners.—The Board of Examiners held 18 meetings during the year, averaging about three hours each. It considered and referred to the Board of Directors with its recommendations a total of 1889 applications of all kinds. In addition to these the Board reviewed or reconsidered 33 applications for a second and third time.

The demand upon the time of the Board has been greater during the past year than in any previous year, owing to the large number of applications filed for admission or transfer to the higher grades. Such applications are considered in great detail and all of the evidence submitted by the applicants, including the record and communications from references and others, is read by the Board.

The result of the Board's work for the year is given in the following tabulated statement:

APPLICATIONS FOR ADMISSION.

Recommended for grade of Associate	1036		
Not recommended for grade of Associate	10	1046	
Recommended for grade of Member	74		
Not recommended for the grade of Member	50	124	
Recommended for grade of Fellow	11		
Not recommended for Fellow	5	16	
Recommended for enrolment as students	576	576	

APPLICATIONS FOR TRANSFER.

Recommended for grade of Member	66		
Not recommended for grade of Member	41	107	
Recommended for grade of Fellow	11		
Not recommended for grade of Fellow	9		20
Total number of applications considered		1889	
Applications reconsidered		33	
Total		1922	

Membership Committee.—The work of the committee has resulted in the filing of 1235 new applications. Much credit for the success of the committee's work is due to the loyal support of the Sections and more particularly the chairmen of the local membership committees.

The following tabulated statement shows the number of members in each grade, the total membership of the Institute on April 30, and the additions and deductions which have been made during the year. It is not intended, however, to show the number of applications received, as a considerable number is still in the preliminary stages and cannot, therefore, be embodied in a list of the members of the Institute.

	Honorary Member	Fellow	Member	Associate	Total
Membership, April 30, 1917.	4	455	1223	7028	8710
Additions:					
Transferred	....	14	76	....	....
New Members Qualified	2	3	66	937	....
Reinstated	....	2	8	54	....
Deductions:					
Died	....	4	7	26	....
Resigned	....	1	3	111	....
Transferred	....	....	4	84	....
Dropped	....	5	27	318	....
Membership, April 30, 1918	6	464	1332	7480	9282

Net increase in membership during the year 572

Deaths.—The following deaths have occurred during the year:

Fellows.—Albert F. Ganz, F. B. H. Paine, John K. Robinson, Karl Von Krogh.

Members.—Harry Bottomley, Eugene F. Roeber, Henry R. Ford, J. G. Lorrain, Osborn P. Loomis, E. W. Stevenson, E. P. Warner.

Associates.—L. R. Pomeroy, S. H. Harvey, Stuart A. Nims, W. K. Kretsinger, P. H. Goodwin, W. S. Horry, Arthur Gunn, William G. Bee, T. Ohta, John Sachs, W. H. Peberdy, George Scharfe, Percy L. Cobb, John Gilmartin, R. C. Carter, Charles O. Smith, William Duddell, John Hesketh, John H. Goehst, Robert L. Stevenson, O. Zell Howard, Bernard W. Capen, Cyril F. Mickler, St. John Chilton, James A. Barkley, Henry N. Brooks.

Total deaths, 37.

Edison Medal.—The Edison Medal for 1916, which had been awarded to Nikola Tesla by the Edison Medal Committee in December of that year "for his early original work in polyphase and high frequency electric currents" was presented to Mr. Tesla with appropriate ceremonies at the Annual Meeting of the Institute held in New York on May 18, 1917.

The Edison Medal for 1917 has been awarded to Col. John J. Carty "for his work in the science and art of telephone engineering," and the

presentation will take place at the Annual Meeting of the Institute which will be held in New York on May 17, 1918.

John Fritz Medal.—The John Fritz Medal for 1917 was awarded to Dr. Henry Marion Howe "for his investigations in metallurgy, especially in the metallography of iron and steel." The presentation was made in the Engineering Societies Building in New York on May 10, 1917.

The John Fritz Medal for 1918 was presented to Mr. J. Waldo Smith in the Engineering Societies Building, New York, at a joint meeting held on April 17, 1918, for "achievement as engineer in providing the City of New York with a supply of water."

Finance Committee.—During the year the committee has held monthly meetings, has passed upon the expenditures of the Institute for various purposes, and otherwise performed the duties prescribed for it in the Constitution and By-laws.

Haskins and Sells, certified public accountants, have audited the books, and their report is included herein. It will be noted that in the report a readjustment of the Institute's equity in the property held in trust by the United Engineering Society has been made, due to the admission of a fourth founder society to the United Engineering Society.

In company with the Secretary, the Treasurer, and a representative of Haskins and Sells, the chairman of the committee examined the securities held by the Institute and found them to be as stated in the accountants' report.

NEW YORK	**HASKINS & SELLS**	SAN FRANCISCO
CHICAGO	CERTIFIED PUBLIC ACCOUNTANTS	LOS ANGELES
DETROIT	CABLE ADDRESS "HASKSELLS"	SEATTLE
ST. LOUIS	30 BROAD STREET	DENVER
CLEVELAND	NEW YORK	ATLANTA
BALTIMORE		WATERTOWN
PITTSBURGH		LONDON

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

CERTIFICATE

We have audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1918, and

We Hereby Certify that the accompanying General Balance Sheet properly sets forth the financial condition of the Institute on April 30, 1918, that the Statement of Income and Profit & Loss for the year ended that date is correct, and that the books of the Institute are in agreement therewith.

HASKINS & SELLS,

Certified Public Accountants.

New York,

May 14, 1918.

AMERICAN INSTITUTE OF

EXHIBIT A. **GENERAL BALANCE SHEET**

ASSETS.

REAL ESTATE:			
One-fourth Interest in United Engineering Society's Real Estate, No. 25 to 33 West 39th Street:			
Land and Building		$472,500.00	
Real Estate Equipment, etc		14,292.79	
Total Real Estate			$486,792.79
EQUIPMENT:			
Library—Volumes and Fixtures		$ 40,031.55	
Works of Art, Paintings, etc		3,001.35	
Office Furniture and Fixtures		12,274.65	
Total		$ 55,307.55	
Less Reserve for Depreciation		9,419.77	
Remainder—Equipment			$ 45,887.78
INVESTMENTS:			
Bonds—City of Wilmington, Delaware, 4½%, 1934, Par Value $15,000.00		$ 15,834.19	
United States Liberty Loan, 4¼% Bonds		10,000.00	
Total Investments			25,834.19
WORKING ASSETS:			
Publications Entitled "Transactions," etc		$ 14,049.00	
Paper and Cover Paper		1,046.28	
Badges		676.70	
Total Working Assets			15,771.98
CURRENT ASSETS:			
Cash		$ 12,270.07	
Accounts Receivable:			
Members for Past Dues		9,559.82	
Advertisers		769.70	
Miscellaneous		470.76	
Accrued Interest on Investments		56.25	
Accrued Interest on Bank Balances		358.66	
Total Current Assets			23,485.26
FUNDS:			
Life Membership Fund:			
Cash	$ 438.67		
Chicago, Burlington & Quincy Railroad Company Bonds, 4%, 1958, Par Value $5,000.00	4,868.75		
Accrued Interest	33.33	$ 5,340.75	
International Electrical Congress of St. Louis—Library Fund:			
Cash	$ 943.99		
New York City Bonds, 4½%, 1957, Par Value $2,000.00	2,248.71		
Accrued Interest	45.00	3,237.70	
MAILLOUX FUND:			
Cash	$ 167.35		
New York Telephone Company Bond, 4½%, 1939	1,000.00		
Accrued Interest	22.50		
		1,189.85	
Midwinter Convention Fund—Cash		163.58	
International Electrical Congress of San Francisco—Cash		40.50	
Total Funds			$ 9,972.38
DUES PAID IN ADVANCE—INTERNATIONAL ELECTROTECHNICAL COMMISSION, LONDON, ENGLAND			500.00
Total			$608,244.38

ELECTRICAL ENGINEERS.

April 30, 1918.

Liabilities

Current Liabilities:		
Accounts Payable—Subject to Approval by the Finance Committee	$ 6,304.01	
Due United Engineering Society Account Building Addition	10,000.00	
Dues Received in Advance	2,382.87	
Entrance Fees and Dues Advanced by Applicants for Membership	179.50	
Total Current Liabilities		$ 18,866.38
Fund Reserves:		
Life Membership Fund	$ 5,340.75	
International Electrical Congress of St. Louis—Library Fund	3,237.70	
Mailloux Fund	1,189.85	
Midwinter Convention Fund	163.58	
International Electrical Congress of San Francisco	40.50	
Total Fund Reserves		$ 9,972.38
Surplus: Per Exhibit "B"		$579,405.62
Total		$608,244.38

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Statement of Income and Profit and Loss.

For the Year Ended April 30, 1918.

Exhibit B.

Revenue:			
Entrance Fees		$ 5,545.00	
Dues		96,897.93	
Student's Dues		3,771.00	
Transfer Fees		940.00	
Advertising		8,189.02	
Subscriptions		3,286.20	
Sales of "Transactions," etc		2,574.24	
Badges Sold	$2,253.75		
Less Cost	1,992.12		
		261.63	
Interest on Investments		675.00	
Interest on Bank Balances		1,027.43	
Exchange		30.74	
Total			$123,198.19
Expenses:			
Meetings and Paper Committee:			
Salaries		$ 5,560.00	
Binding and Mailing Proceedings		4,384.97	
Printing Proceedings		6,052.07	
Engraving Proceedings		1,523.22	
Paper and Cover Paper		4,581.05	
Envelopes		723.20	
Stationery and Miscellaneous Printing		177.96	
General Expenses		250.35	
Meetings		3,193.14	
Editing Committee:			
Volume No. 34		136.22	
Volume No. 35		12,370.15	
Volume No. 36		5,372.29	
Total		$ 44,324.62	
Deduct Increase in Inventory of Publications:			
April 30, 1917	$12,884.25		
April 30, 1918	14,049.00	1,164.75	$43,159.87
Executive Department:			
Salaries		$ 17,698.50	
General Expenses		2,737.33	
United Engineering Society—Assessments		4,800.00	
Express		311.13	
Postage		1,980.65	
Advertising		2,623.74	
Stationery and Miscellaneous Printing		3,027.68	
Year Book and Catalgue		3,487.90	
Office Furniture and Fixtures—Discarded		51.20	
Total			36,718.13
Sections Committee:			
Section Meetings		$ 6,162.15	
Branch Meetings		208.85	
Salaries, New York Office		2,340.00	
Stationery and Printing, New York Office		698.70	
Express on Advance Copies		8.09	
Total			$ 9,417.79
Forward			$ 89,295.79
Revenue—(Forward)			$123,198.19

REVENUE—(Forward)			$123,198.19
EXPENSES—(Forward)			$ 89,295.79
General:			
Library Committee		$ 4,000.01	
Membership Committee		1,079.38	
Finance Committee		150.00	
Standards Committee		1,221.72	
Code Committee		30.00	
Annual Dues, International Electrotechnical Commission		250.00	
National Defense—Miscellaneous Expenses		1,488.42	
John Fritz Medal Award		94.00	
Honorary Secretary		4,000.00	
United Engineering Society, Engineering Council		1,600.00	
American Engineering Standards Committee		359.37	
Membership Classification Service		776.65	15,049.55
Total			$104,345.34
Deduct:			
Decrease in Accounts Payable—Subject to Approval by the Finance Committee, Expenses Undistributed at:			
May 1, 1917—As Adjusted		$ 7,869.81	
April 30, 1918		6,304.01	1,565.80
Total Expenses			$102,779.54
NET REVENUE			$ 20,418.65
PROFIT AND LOSS CREDITS:			
Accessions to Library Volumes and Fixtures		$ 151.75	
Refund of Unexpended Balance of Contribution of American Institute of Electrical Engineers to proposed International Electrical Congress 1915		321.99	
Total			473.74
GROSS SURPLUS FOR THE YEAR			$ 20,892.39
PROFIT AND LOSS CHARGES:			
Uncollectible Dues Written Off		$ 4,003.75	
Provision for Depreciation of Furniture and Fixtures		1,393.49	
Amortization of Premium on City of Wilmington, Delaware—4½% Bonds of 1934		52.14	
Total			5,449.38
NET SURPLUS FOR THE YEAR			$ 15,443.01
SURPLUS, May 1, 1917		$623,016.43	
ADD—REAL ESTATE EQUIPMENT AND PRELIMINARY EXPENSES CREDITED TO THE INSTITUTE BY THE UNITED ENGINEERING SOCIETY BUT NOT HERETOFORE SHOWN ON THE BOOKS		15,710.44	
Total		$638,726.87	
DEDUCT:			
Value of Equity Adjusted to One-fourth Interest:			
Real Estate Equipment, etc.	$ 4,764.26		
Land and Building	132,500.00		
Total	$137,264.26		
Less Increase in Equity in Building by Addition of Three Stories	62,500.00		
Net Adjustment of Equity Value		74,764.26	
Surplus as Adjusted			563,962.61
SURPLUS, APRIL 30, 1918			$579,405.62

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Statement of Cash Receipts and Donations for Designated Purposes. Also Disbursements, for the Year Ended April 30, 1918.

Exhibit C.

Receipts:	
Life Membership Fund	$217.68
International Electrical Congress of St. Louis Library Fund—Interest and Royalties	93.40
Mailloux Fund—Interest	45.00
Midwinter Convention Fund—Contributions and Interest	74.53
Total	$430.61
Disbursements:	
Life Membership Fund	217.68
Midwinter Convention Fund	6.75
Total	$224.43

RECEIPTS AND DISBURSEMENTS PER YEAR PER MEMBER.

During each fiscal year for the past eight years.

Year ending April 30	1911	1912	1913	1914	1915	1916	1917	1918
Membership, April 30, each year	7117	7459	7654	7876	8054	8212	8710	9282
Receipts per Member	$13.37	$13.19	$13.45	$14.08	$14.06	$13.62	$13.30	$13.17
Disbursements per Member	11.03	12.44	15.57	12.86	13.54	13.74	12.75	11.99
Credit Balance per Member	$2.34	$ .75	*$2.12	$1.22	$ .52	*$ .12	$ .55	$1.18

*Deficit.

Respectfully submitted for the Board of Directors,

F. L. HUTCHINSON, *Secretary.*

New York, May 17, 1918.